AUGUST 1961
Volume 198 Part 4

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*Incorporated by Royal Charter 1899*

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# JOURNAL OF THE IRON AND STEEL INSTITUTE

# D.L.P. LOW POROSITY LADLE BRICKS within 24 hours . . .

Proved in service by continued and increasing steelworks demand.

Photograph by courtesy of The Briton Ferry Steel Co. Ltd.

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From our large output of Low Porosity Ladle Bricks, all palletized, we can deliver to you **in any part of the country within 24 hours.**

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Once again Henry Wiggin & Company Ltd. order

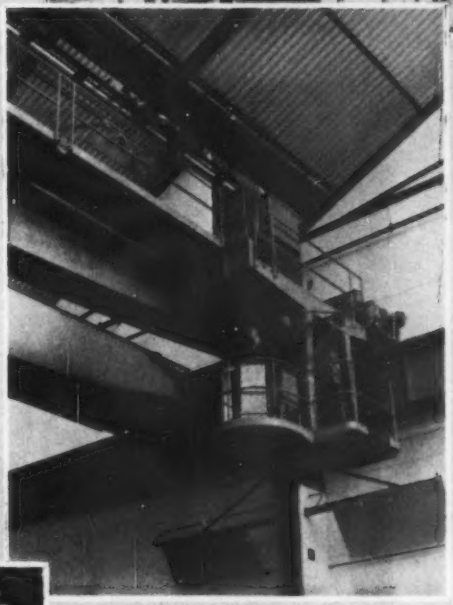
# WELLMAN CRANES

## for their works at Hereford

Henry Wiggin & Company Ltd., of Birmingham, Leading Nickel and Nickel Alloy Steel Manufacturers, continue to rely on Wellman Cranes.

Dependability, the hallmark of Wellman Cranes, is the very essence of continued full production.

First rate design team, three well-equipped manufacturing works, and complete shop erection before delivery to site, combined with many years of experience in both design and application, form the background of modern Wellman Cranes.



The photographs, by courtesy of Henry Wiggin & Company Ltd., show our latest box plate type girder resulting in low overall weight, high-speed travel and pleasing clean-cut design. The machine has a main hoist capacity of 15 tons, with auxiliary hoist capacity of 5 tons, has a span of 77 feet at a height of 25 feet above floor level.

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PARNELL HOUSE, WILTON ROAD, LONDON, S.W.1 WORKS: DARLASTON, South Staffs, & BELFAST.

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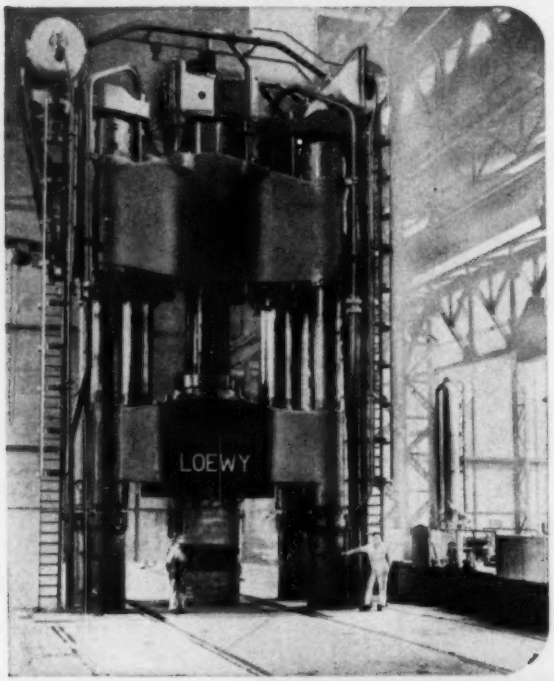


6000 tons Forging press

By courtesy of The Rotterdam Dockyard Company Limited.)

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*FORGING*
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*PIERCING*
*DRAWING*
*UPSETTING*
*FLANGING*
*POWDER*
*CARBON ELECTRODE*
*MULTI-DAYLIGHT*
*RING ROLLING*

*for the ferrous and non-ferrous industries*

2000 tons Extrusion press

(By courtesy of James Booth Aluminium Limited.)

THE LOEWY REG'D TRADE MARK ENGINEERING COMPANY LTD.
BOURNEMOUTH ENGLAND

# ☛STELVETITE–
# plastic bonded to steel has put a new face on the SADIA TWO-PLUS Water Heater

The use of Stelvetite in the manufacture of the Sadia Two-Plus provides a perfect example of the economy it achieves. Aidas Electric Ltd. decided to open a satellite factory at Salisbury to make this popular heater. The factory was planned around the exclusive use of Stelvetite for casings, thus eliminating the need for a paint shop because Stelvetite has a finished surface.

As a result capital costs were cut by 17½% and production started three months earlier than would otherwise have been possible. This economy is additional to the cost and time saved in actual manufacture

The P.V.C. surface of Stelvetite is impervious to superficial knocks, chips and scratches, yet it is decorative, heat resistant, an insulation and its colour holds fast.

Stelvetite

Plastic bonded to Steel

* *Accepted by the Council of Industrial Design for "Design Index"*

All enquiries about the Sadia Two-Plus Water Heater should be addressed to Aidas Electric, Sadia Works, Rowdell Road, Northolt, Middlesex.

*STELVETITE—made in co-operation with BX Plastics Ltd. by

**JOHN SUMMERS & SONS LTD**

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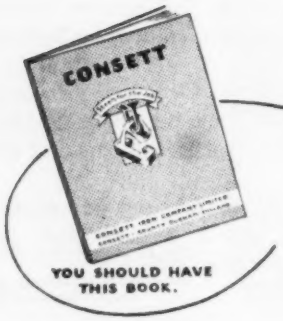
## and our trade is STEEL!

Not only mild steel for everyday use but also the special steels demanded by the Nuclear Age . . .

Consett nuclear steels were selected for use in the British Nuclear Plants at Bradwell, Chapel Cross, Calderhall and now Dungeness, as well as the new Italian plant at Latina.




*An interesting booklet "Steels for the Job", published by us, describes some of our newer products. We shall be delighted to send you a copy.*

*Our Technical and Research Department will also welcome enquiries from any whose problem is . . .* **STEEL**

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incorporating W.T.SEYMOUR (STOCKTON) LTD.
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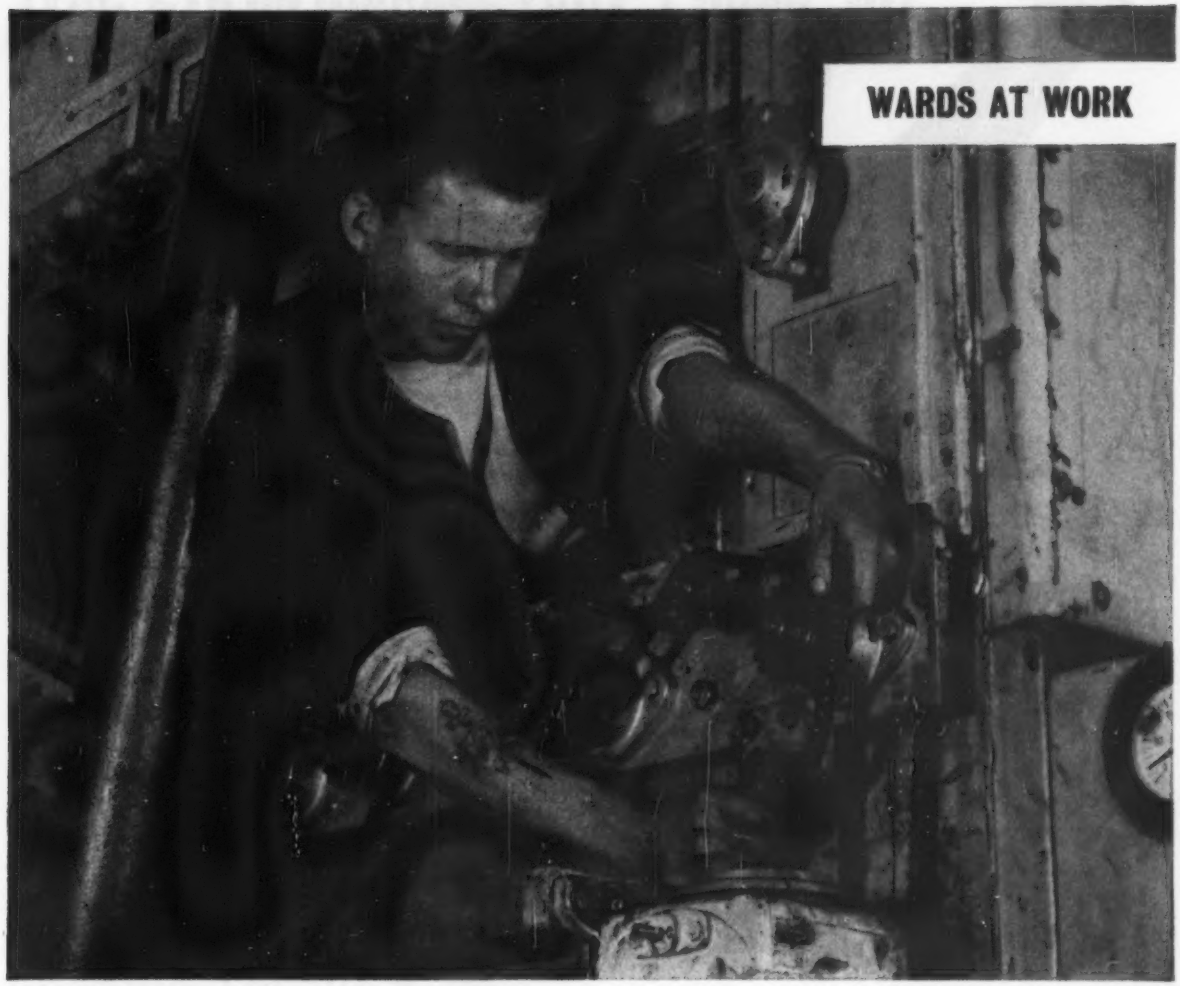
## A New High Duty Universal Beam Mill in Great Britain

**APPLEBY-FRODINGHAM STEEL COMPANY (branch of the United Steel Companies Limited) has recently commissioned a new universal beam mill at Scunthorpe. It is to be used for the production of universal wide flange beams with parallel flanges ranging from 8" x 5¼" to 24" x 9", universal columns up to 12" sizes and a corresponding range of light beams. The mill consists of a universal roughing group, finishing stand, roller tables, skid transfers and a saw line and is engineered throughout on advanced lines. A wide measure of automatic control is provided: there are means for quick roll changing and all rolls are carried in roller bearings. SCHLOEMANN were the designers and main contractors for this mill, which was manufactured at the Workington plant of DISTINGTON ENGINEERING COMPANY LIMITED (a subsidiary of the United Steel Companies Limited). Through the excellent co-operation of the firms concerned, delivery was made in a comparatively short time and the plant was put into operation on schedule.**

Photographs by courtesy of Appleby-Frodingham Steel Company

**DOLLERY & PALMER LTD · 54, Victoria Street LONDON SW 1 · Lydgate Lane SHEFFIELD 10**

# THE MONEY THAT MANAGEMENTS SAVE




G.P. 99

## House movers to industry!

He and his team mates are experts at moving plant of every description and such problems as weight, bulk, low headroom, are handled with a skill born of long experience. In this case an oven is being reassembled as part of a big re-organisation at Bondina (B.D.A) Works. Wards' Factory Planning and Installation Department offer a complete service for the planning of new factory layouts, dismantling, transportation and reinstallation, even repositioning of power supplies and services — all with minimum interruption to production. Factory Planning and Installation is only one activity of the Ward Group of Companies, whose products and services cover almost every branch of industry.

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# THE MONEY THAT MANAGEMENTS SAVE THROUGH MOBIL ECONOMY SERVICE

## More than £6,000 a year at Kellogg Company of Great Britain Limited

KELLOGG COMPANY OF GREAT BRITAIN LTD found that the roll neck bearings used in flake roll machines were averaging only two months' life. So they took their problem to the experts in lubrication—Mobil. Mobil advised the installation of mechanical grease pumps using a special grade of Mobilgrease. The annual cost of replacing the bearings of each of the flake rolls has been £312 . . . but since the introduction of Mobilgrease the life of the bearings has been considerably extended, and there has been no loss of production time through bearing failure. During one year of operation, after applying Mobil's suggestions, Kellogg's made a direct saving of over £6,000 in replacements, maintenance, and production time.

**WORLD-WIDE EXPERIENCE OF INDUSTRIAL LUBRICATION** This example of the value of Mobil Economy Service is typical of many that could be cited from almost every industrial area of the world. In all these areas, the world-wide Mobil organisation is applying more than 90 years' experience to the cutting of lubrication and maintenance costs.

**ONE PLAN TO MEET ALL LUBRICATION NEEDS** The value of Mobil Economy Service is the value of expert knowledge methodically applied; it is a matter of assessing all the lubrication needs of a business collectively, considering how they can best be met with the fewest different lubricants in the smallest quantities, and making sure that everyone concerned knows how to use the lubricants to the best effect with the absolute minimum of work. The astonishingly large savings that are often achieved are the measure of the experience and skill that Mobil bring to the consideration of every industrial lubrication problem.

Mobil
ECONOMY SERVICE

## *Let them drop to your very great advantage*

## –with Therbloc

Therbloc enables you to drop a layer of bricks—*refractory bricks*—not just ordinary bricks like these. Reason lies in Therbloc's supremely high insulation efficiency. A thin layer of Therbloc mineral fibre insulating slab ousts a far thicker layer of brickwork. Subsequently thinner refractory wall boosts hearth capacity for a given base area and cuts construction costs. More, Therbloc slims the weight of brickwork to be heated and cooled. Fuel costs decelerate. Cycle times accelerate. So if you'd like to drop a lot of bricks drop us a few lines—our reply will be rewarding.

**STILLITE INSULATION**

Regd. Trade Mark

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Joists, Sections, Bars, T.H. Yielding Arches.

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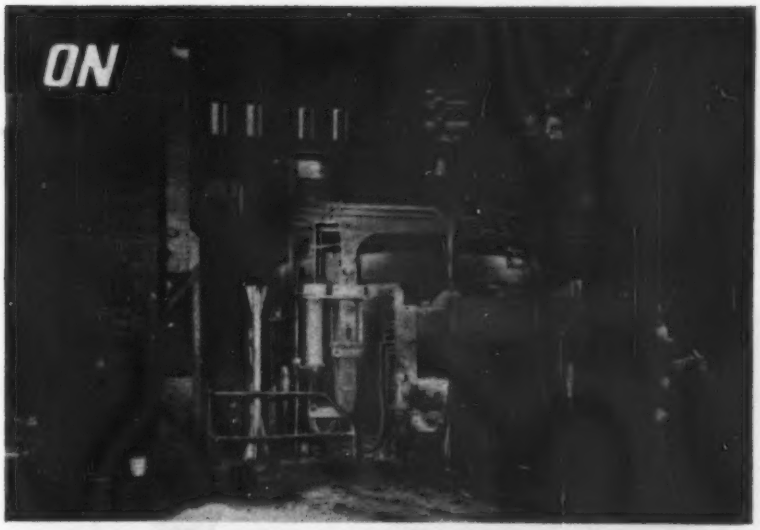
# DIRECT FUME EXTRACTION

## from electric arc furnaces

**EXTRACTION SYSTEM**




These photographs show the direct extraction system on a 40-ton electric arc furnace at Brymbo Steel Works (Branch of the G.K.N. Steel Company Limited). The complete absence of fume at the furnace when the system is in operation is clearly shown.

**EXTRACTION SYSTEM**

# OTHER ORDERS INCLUDE

**STEEL PEECH & TOZER**

Direct fume extraction from two 110-ton furnaces—including gas cleaning plant.

**THOS. FIRTH & JOHN BROWN LTD**

Direct fume extraction from a 40-ton furnace—including gas cleaning plant.

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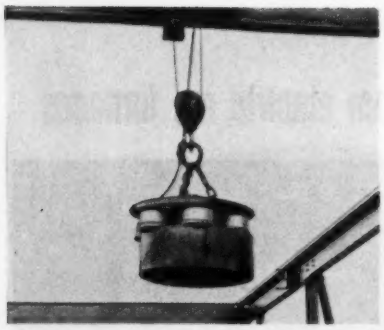
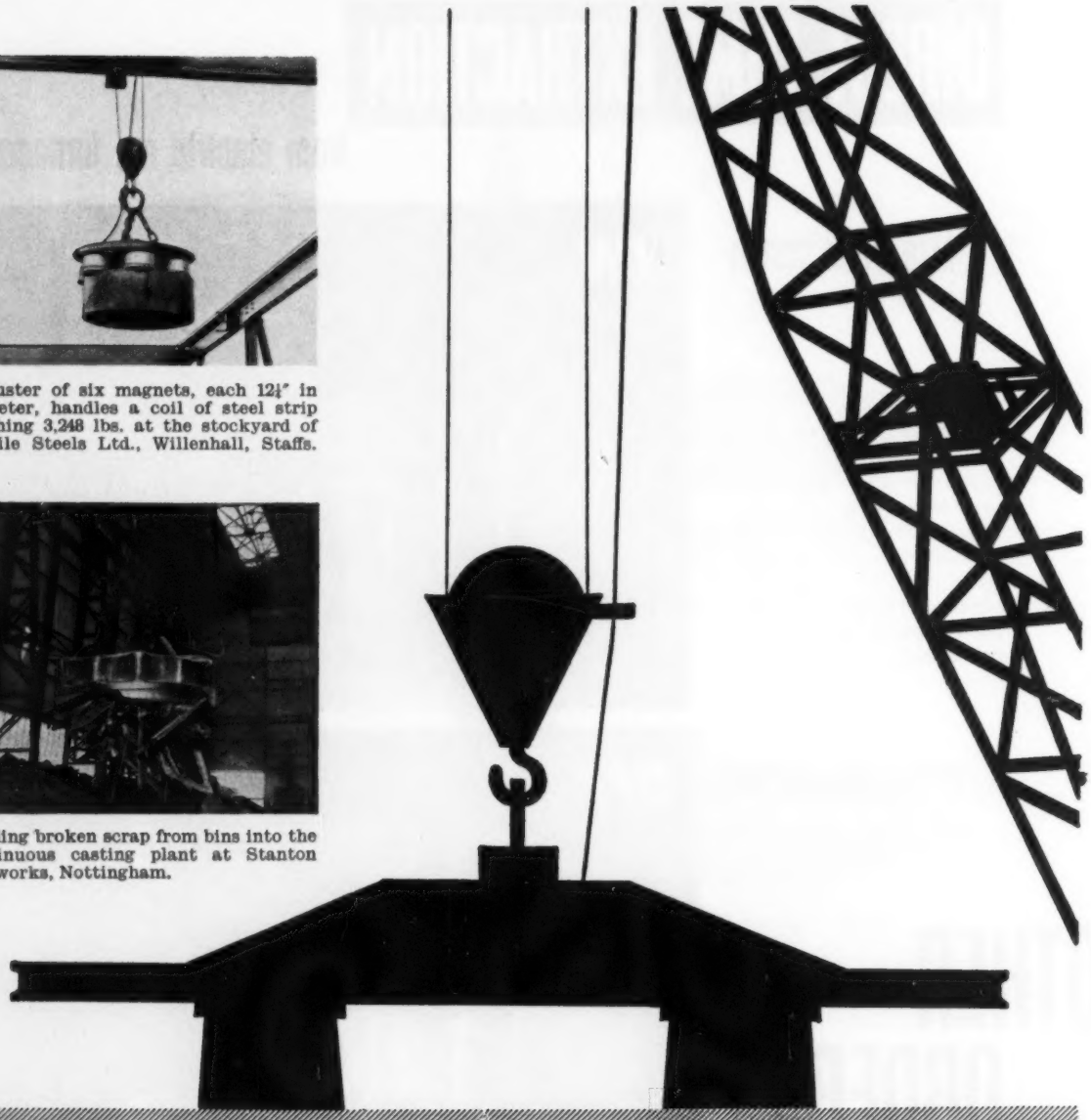
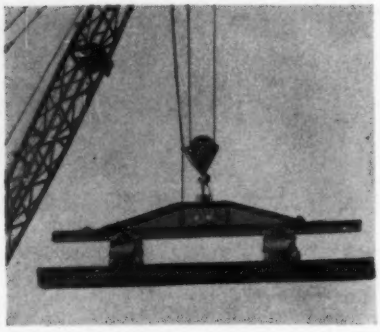


A cluster of six magnets, each 12¼" in diameter, handles a coil of steel strip weighing 3,248 lbs. at the stockyard of Ductile Steels Ltd., Willenhall, Staffs.

Loading broken scrap from bins into the continuous casting plant at Stanton Ironworks, Nottingham.



# WITTON-KRAMER LIFTING MAGNETS FOR EVERY JOB



Two bi-polar magnets on spreader beam lifting rolled steel joist.

Whether handling hot steel billets and ingots or salvaging metal from under water, Witton-Kramer electric magnets do the job superbly. Circular, rectangular or bi-polar, G.E.C. makes them all with coils designed and constructed to withstand heavy duty and shock loads. All Witton-Kramer magnets are easily maintained and quickly serviced.

**RELY ON THE EXPERIENCE OF G.E.C.**

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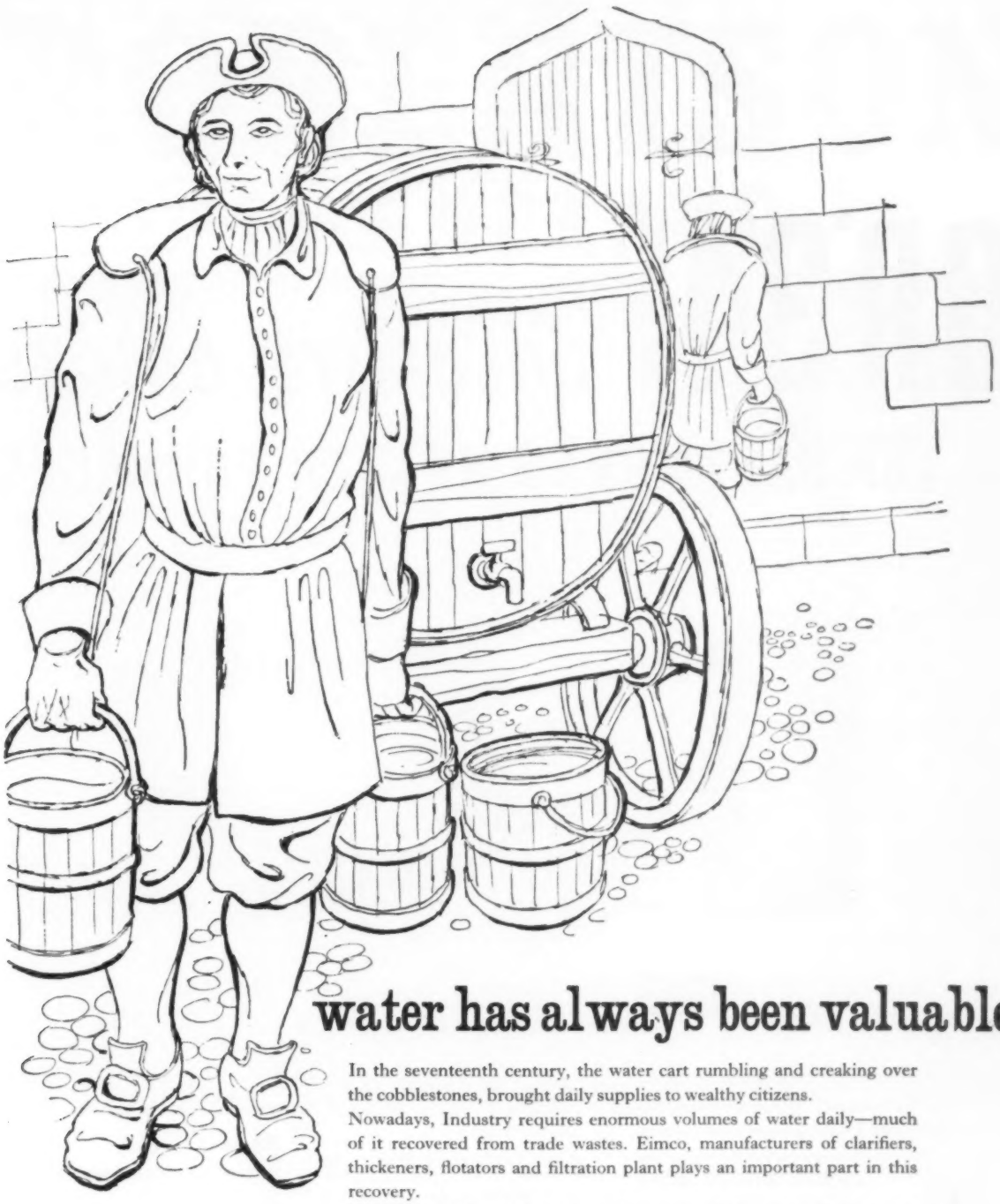

# water has always been valuable

In the seventeenth century, the water cart rumbling and creaking over the cobblestones, brought daily supplies to wealthy citizens.

Nowadays, Industry requires enormous volumes of water daily—much of it recovered from trade wastes. Eimco, manufacturers of clarifiers, thickeners, flotators and filtration plant plays an important part in this recovery.

Eimco's facilities include testing, process design, manufacture and installation. Why not discuss your effluent problem with us?

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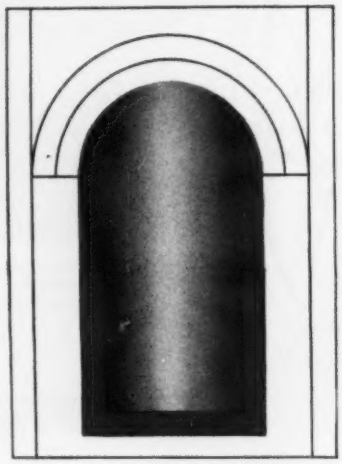
P.3457

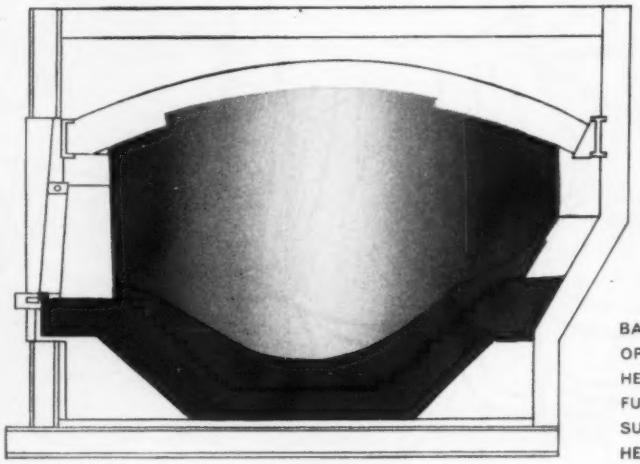
**'341'** DOLOMITE bricks are manufactured from a dolomitic limestone which in the natural state approaches in chemical composition the mineral dolomite $CaCO_3$. $M_3CO_3$. The raw dolomite is dead-burned at high temperatures and it is then formed into suitable shapes, by a new and unique brick-making process. Tunnel kiln firing at high temperatures produces a dense, volume stable and truly basic refractory of exceptional quality. '341' DOLOMITE bricks are resistant to hydration and they can be transported and stocked in the same way as other basic bricks. '341' DOLOMITE bricks are manufactured in various sizes designed to suit many applications.

# G.R.'341' DOLOMITE BRICKS

## for BASIC OPEN HEARTH FURNACES



BASIC OPEN HEARTH SLAG POCKET



BASIC OPEN HEARTH FURNACE SUB HEARTH

'341' DOLOMITE BRICKS
RAMMED DOLOMITE

*'341' DOLOMITE bricks have proved to be ideal for use in modern O.H. units, particularly in sub hearths and slag pockets. In slag pockets these bricks contain the slag during operation — but form a means of speeding up slag removal at the end of the campaign. ('341' bricks hydrate with water to disrupt and break up the slag.)*

### Typical Chemical Analysis

| $SiO_2$ | $TiO_2$ | $Fe_2O_3$ | MnO | $Al_2O_3$ | CaO | MgO |
|---|---|---|---|---|---|---|
| 2/3% | 0.2% | 1/2% | 0.1% | 1/2% | 48/50% | 36/40% |

### Typical Physical Properties

| | |
|---|---|
| TRUE POROSITY % | 18/20 |
| BULK DENSITY grams per c.c. | 2.70/2.75 |
| SPECIFIC GRAVITY | 3.35 |
| SPECIFIC HEAT | 0.25 |
| PERMEABILITY c.g.s. units | 0.05 |
| COLD CRUSHING STRENGTH p.s.i. | +8,500 |
| Kilos sq.cm. | + 600 |
| SPALLING INDEX (small prism test) | Cycles +30 |
| PERMANENT LINEAR CHANGE 2 hrs. at 1,500°C. | Nil to 0.2% |
| WEIGHT PER CUBIC FOOT | 175 lbs. |
| WEIGHT PER CUBIC METRE | 2,700 kilos. |
| WEIGHT PER 1,000 BRICKS 9" x 4½" x 3" approx. | 11,700 lbs. |
| „ | 5,300 kilos. |

*The GENEFAX GROUP for Everything in Refractories*

Please contact our Technical Service Department for further particulars of these and other applications for G.R. '341' bricks.

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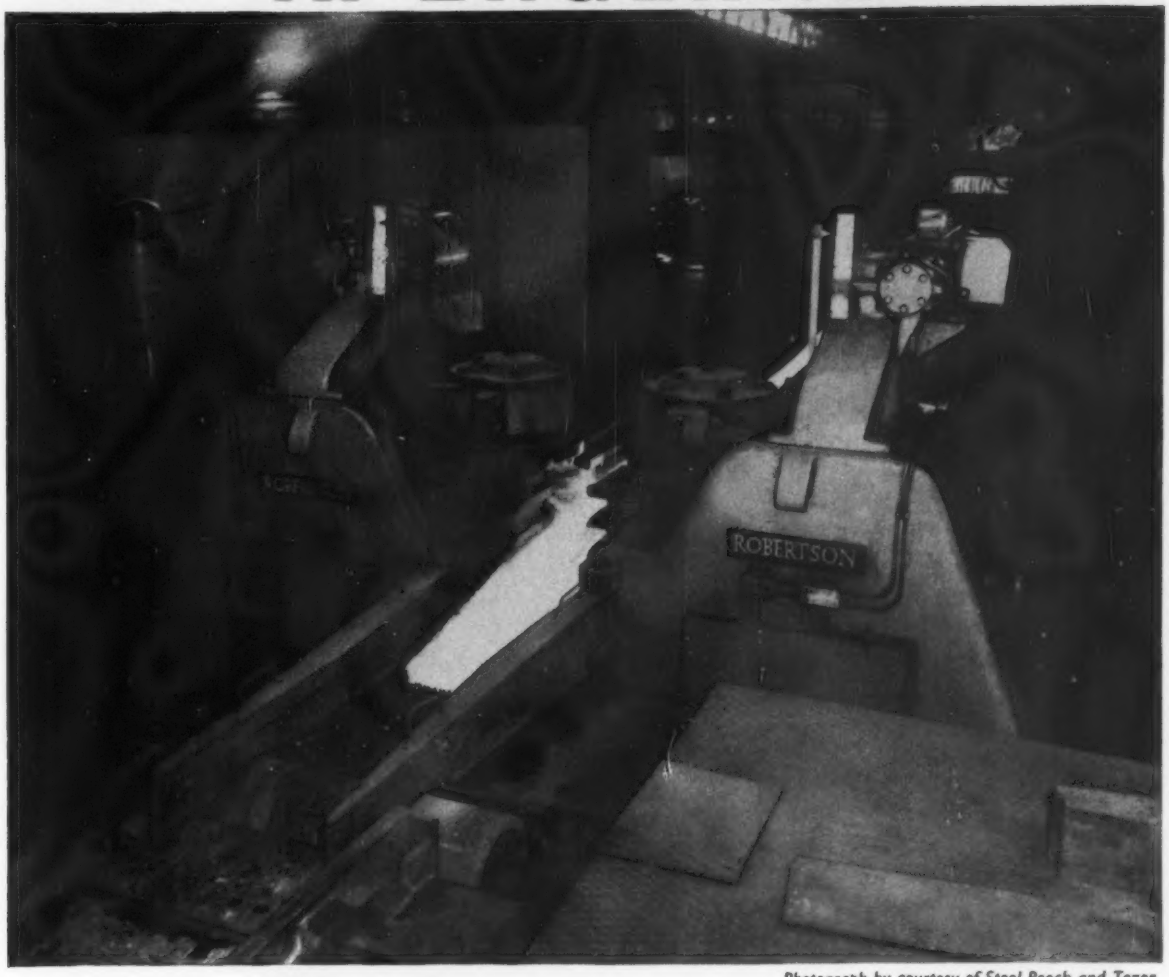
# ROBERTSON
## in ENGLAND




*Photograph by courtesy of Steel Peech and Tozer.*

**Vertical Edging Mill designed and built by Robertsons for Messrs. Steel Peech and Tozer, Rotherham.**

We also manufacture hot and cold rolling mills, pickling lines, flattening and shearing machines, slitting machines, straightening machines, swaging machines, tube making machinery, wire drawing machines, and other metal working equipment.

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CONSISTENT IN TEXTURE...

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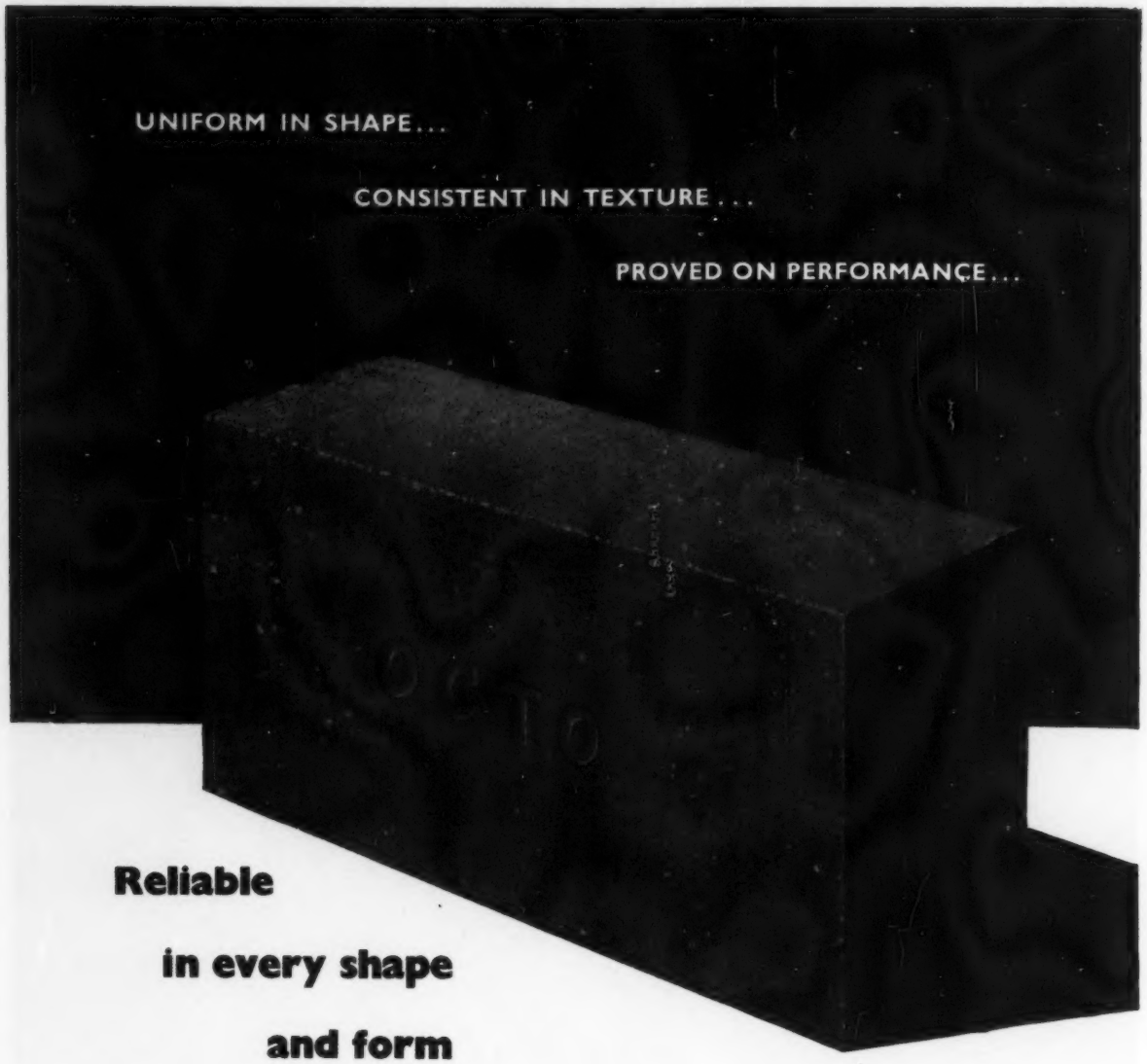


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**in every shape**

**and form**

'OCTO' Brand is the stable firebrick needed in exacting situations. It combines very high refractoriness with superior resistance to corrosive slag attack and to thermal shock – characteristics which contribute to its outstanding success in reheating furnaces, open-hearth regenerator checkers and other high temperature zones.

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The Bonnybridge range also includes the NOVO brands, devised for the severest conditions, CALDER L for steel ladles, CALDER and BONNYBRIDGE BRAND for various furnace applications and a number of cements and castables such as the BONCRETES

**BONNYBRIDGE SILICA & FIRECLAY CO. LTD.** BONNYBRIDGE SCOTLAND

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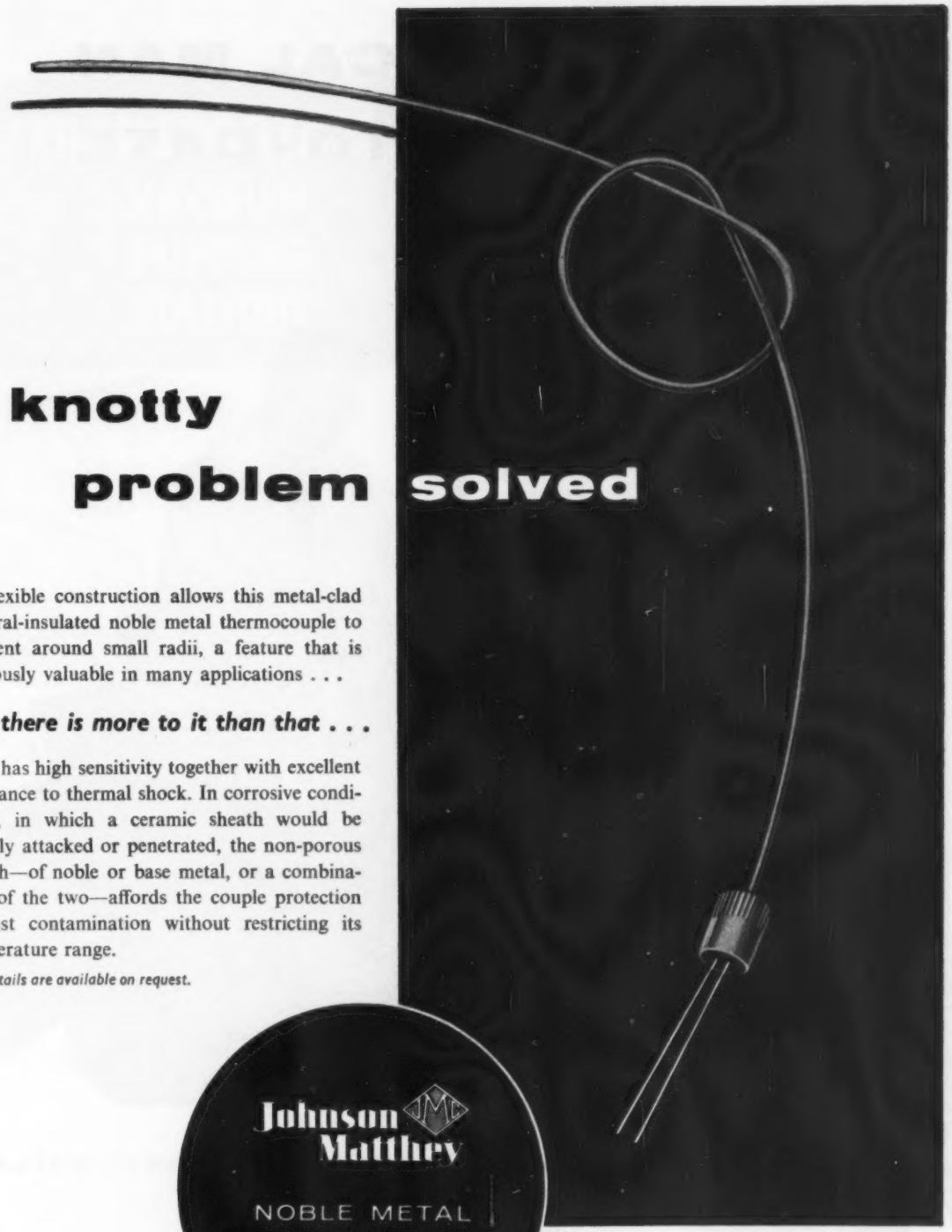

# a knotty problem solved

Its flexible construction allows this metal-clad mineral-insulated noble metal thermocouple to be bent around small radii, a feature that is obviously valuable in many applications . . .

***but there is more to it than that . . .***

for it has high sensitivity together with excellent resistance to thermal shock. In corrosive conditions, in which a ceramic sheath would be rapidly attacked or penetrated, the non-porous sheath—of noble or base metal, or a combination of the two—affords the couple protection against contamination without restricting its temperature range.

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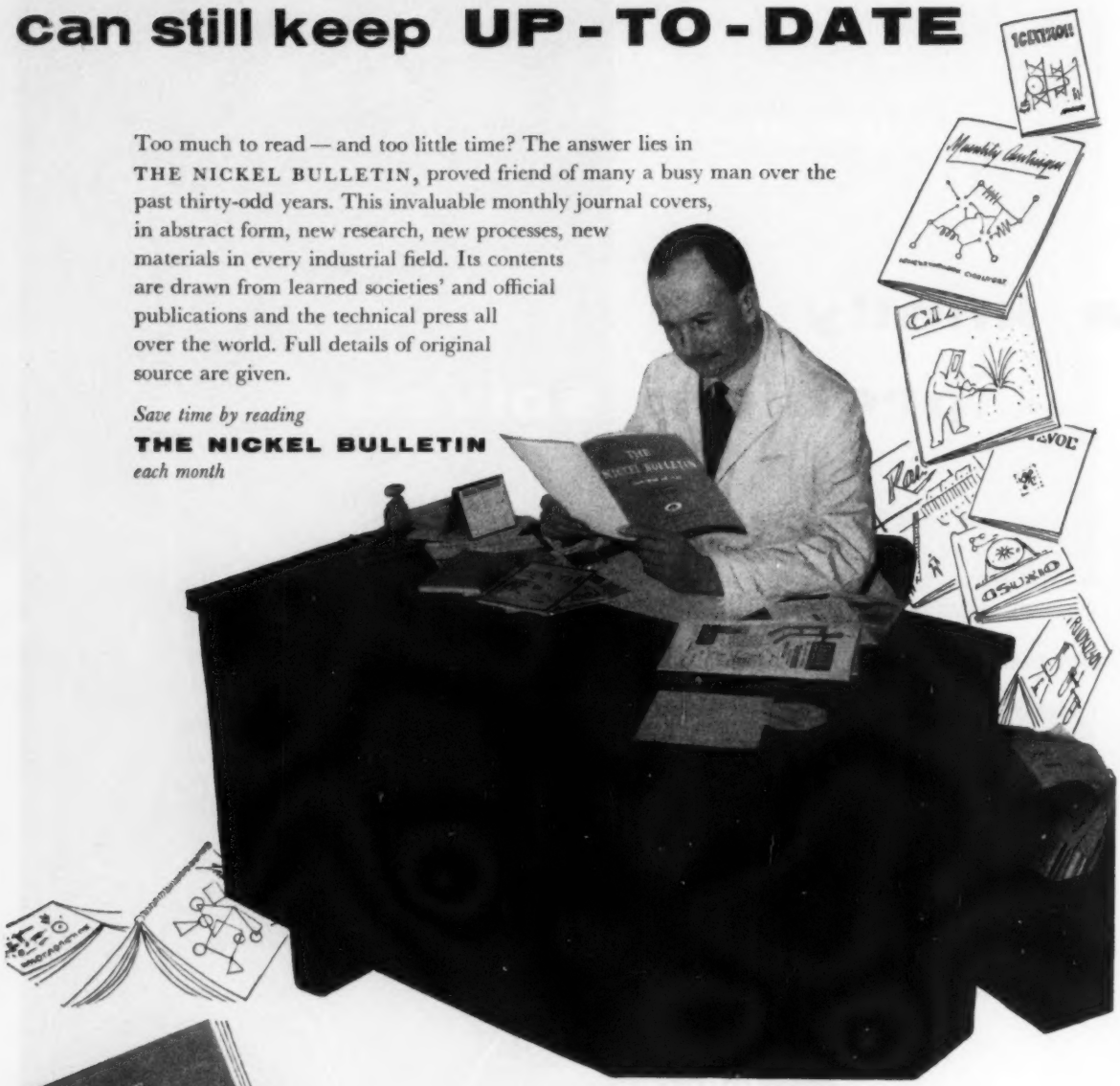

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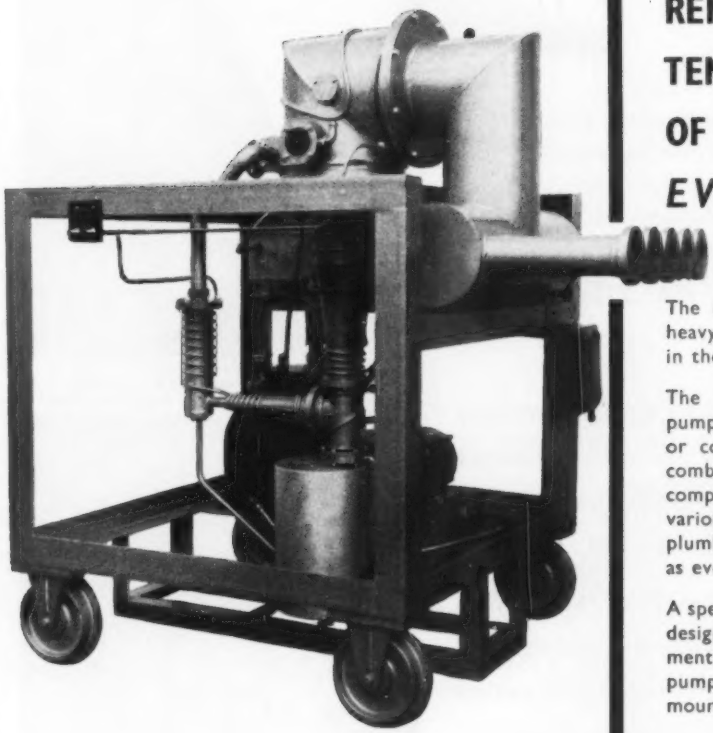
# TRANSPORTABLE VACUUM PUMPING STATIONS



## DEVELOPED TO REMOVE TENS OR TENS OF THOUSANDS OF LITRES OF GAS *EVERY SECOND!*

The use of high vacuum pumping stations is heavy industry's latest move to speed things up in the laboratory and on the factory floor.

The wide range of standard 'SPEEDIVAC' pumping systems includes single rotary pumps or combined rotary and diffusion pumps, or combined rotary and high speed booster pumps complete with vacuum gauges, valves and various controls, as required. There are no plumbing or constructional duties to carry out as every system is fully valved ready for use.

A specially constructed unit is shown which was designed for use with vacuum annealing equipment. It comprises both rotary and booster pump complete with control valves and gauges, mounted on a mobile frame.

## "SPEEDIVAC" MOBILE PUMPING UNITS

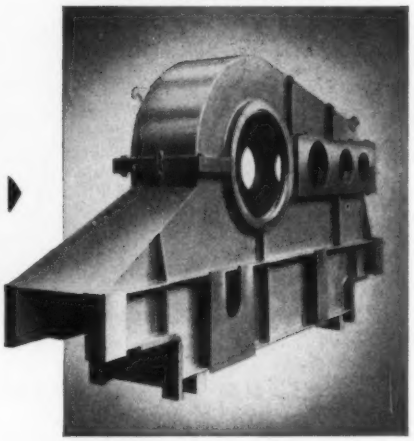
EDWARDS HIGH VACUUM LTD | MANOR ROYAL | CRAWLEY Crawley 1500 | SUSSEX | ENGLAND

# *Craneage for the Steel Industry*

A 130/40 tons heavy duty electric overhead travelling crane handling forgings in the Bessemer Heat Treatment Department at Messrs. Thos. Firth & John Brown Ltd., Sheffield.

Upper photograph by courtesy of Messrs. Thomas Firth & John Brown Ltd.

Fabricated steel gearboxes are a salient feature of Clyde-Booth practice. In this example the gearbox and crab side members form a monobloc box-section of great strength and rigidity.



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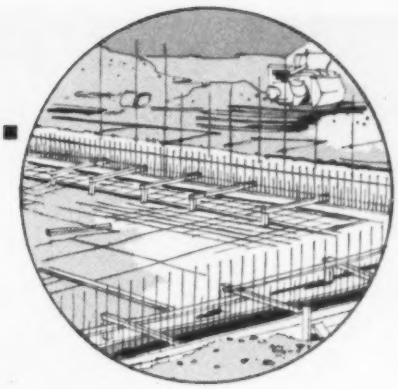

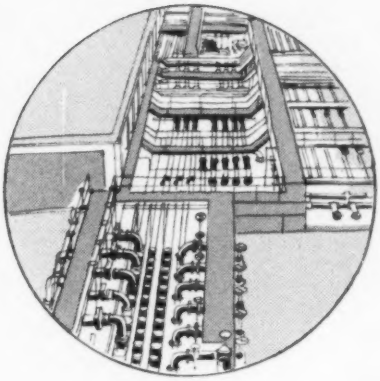

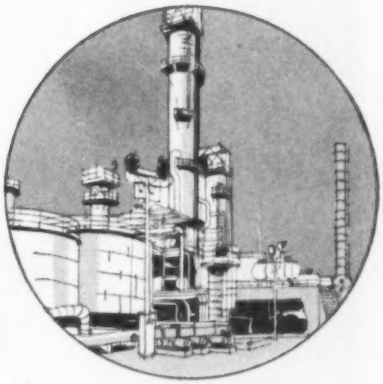

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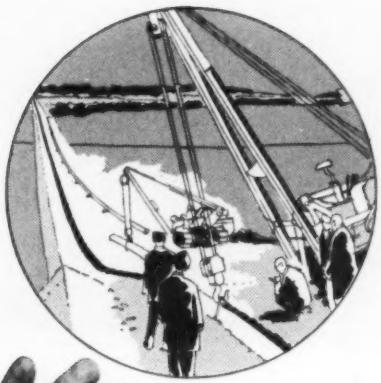

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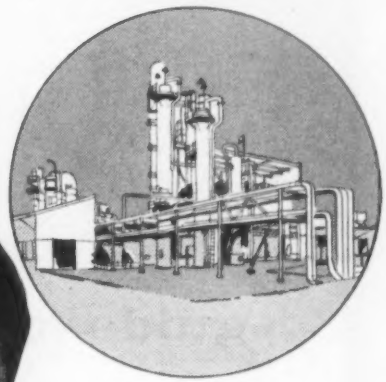

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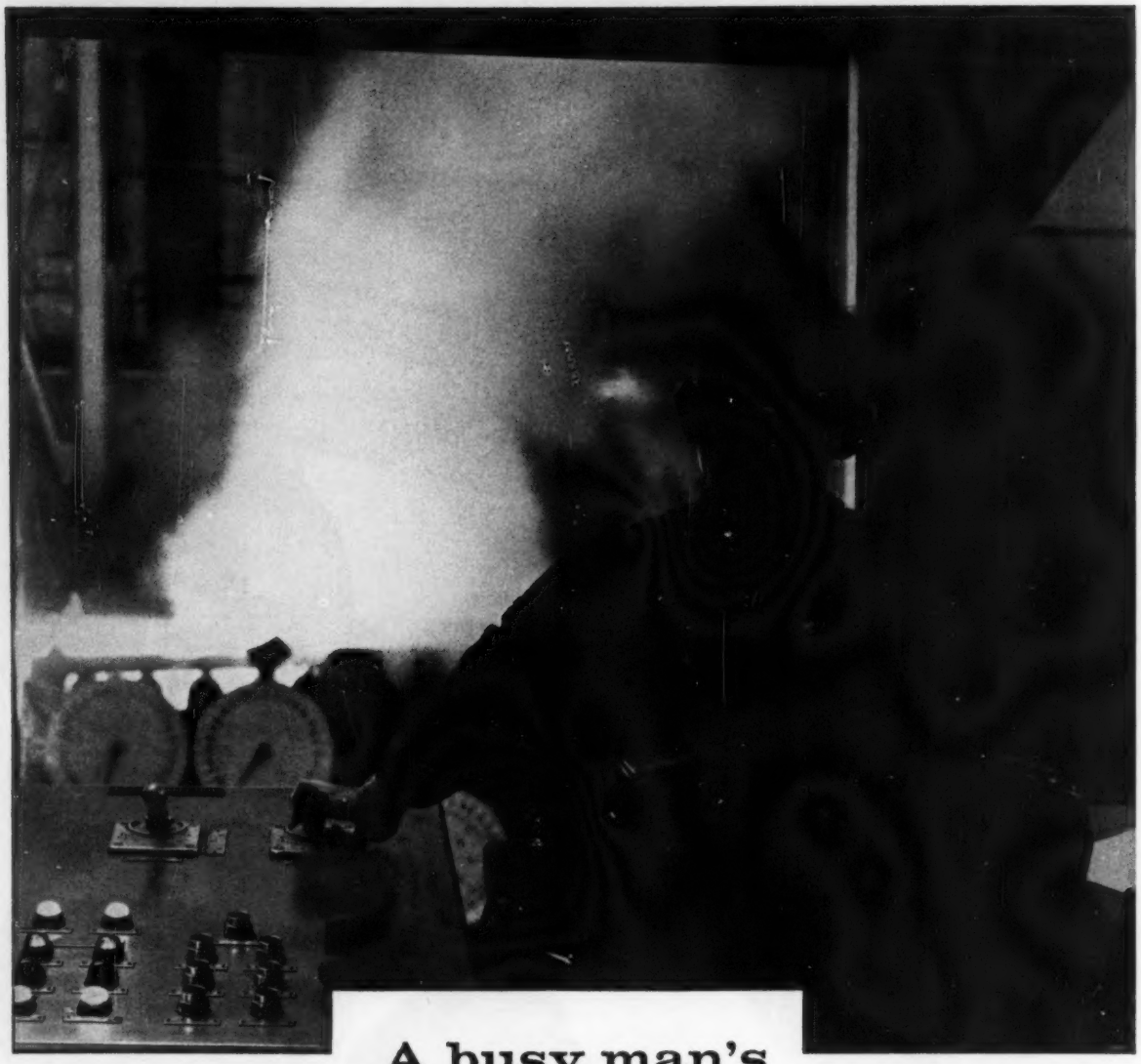

# A busy man's guide to Britain's steel progress

WINSTON CHURCHILL kept his finger on the pulse of things by asking for important information "on one side of a sheet of paper".

The post-war achievements of the British steel industry would fill a book. Here, for the busy man whose eye we have this minute, is an account of what is happening now.

**PRODUCTION** The British steel industry produced over 24 million tons of steel in 1960 – compared with 20 million tons in 1959. Output is now about *double* the pre-war figure. Production of alloy steels – especially stainless steel – is expanding particularly rapidly.

**PLANT** Since the end of 1946, over £900,000,000 has been spent on development. Continued modernisation and expansion – now costing some £200,000,000 a year – will provide steel capacity for over 34 million tons by 1965. Pig iron output per furnace and open hearth steel output per furnace are both more than double pre-war. With the need for ever-increasing efficiency and economy, ore beneficiation has made great strides and fuel consumption per ton of iron has been reduced by about 25% since the war. Use of oxygen for steelmaking is rapidly increasing.

**INDUSTRIAL RELATIONS** The industry keeps its remarkably good record for settling industrial disputes without recourse to strike action. British steel workers are often sons and grandsons of steel workers, richly endowed with traditional skills. Making steel exactly to specification is more than a commercial requirement; it's a matter of pride.

**PRICES** British steel prices have been keenly competitive since the war with those of other major European producers and well below the American price level – and the quality of British steel is unsurpassed.

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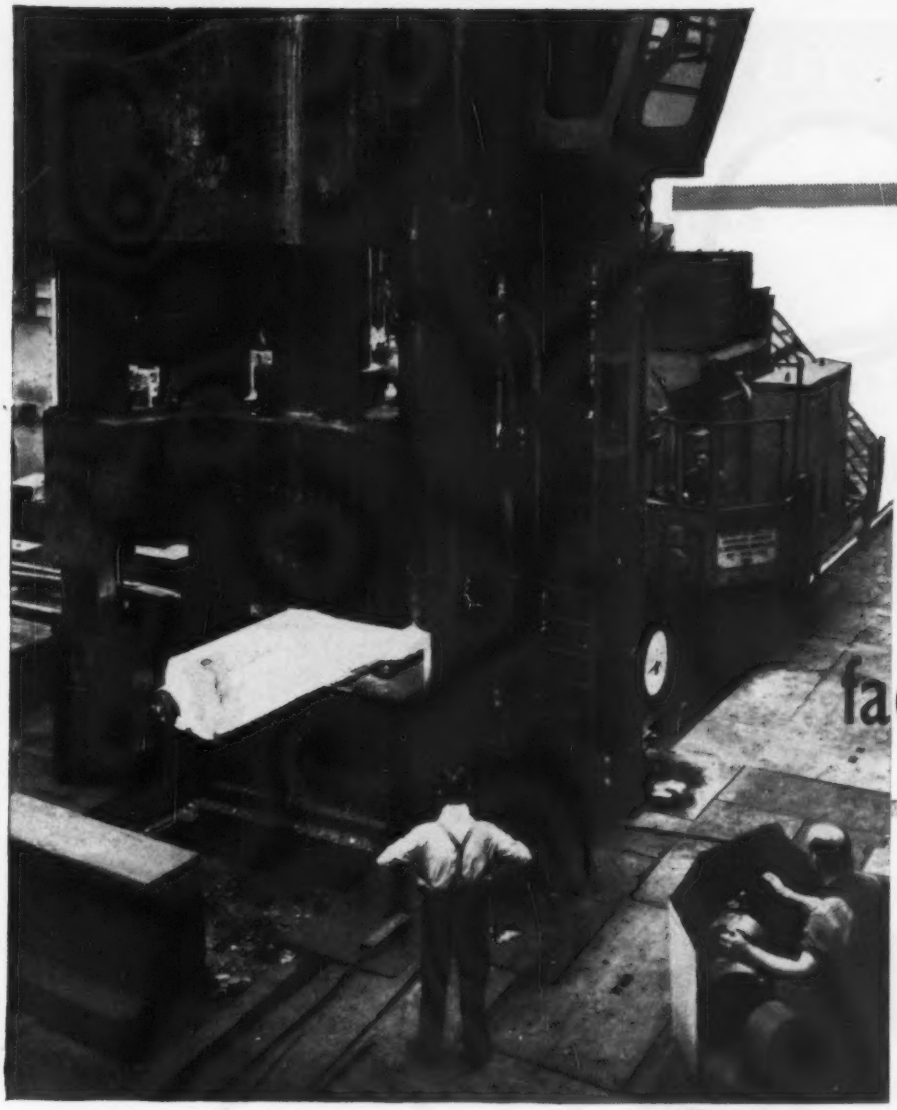

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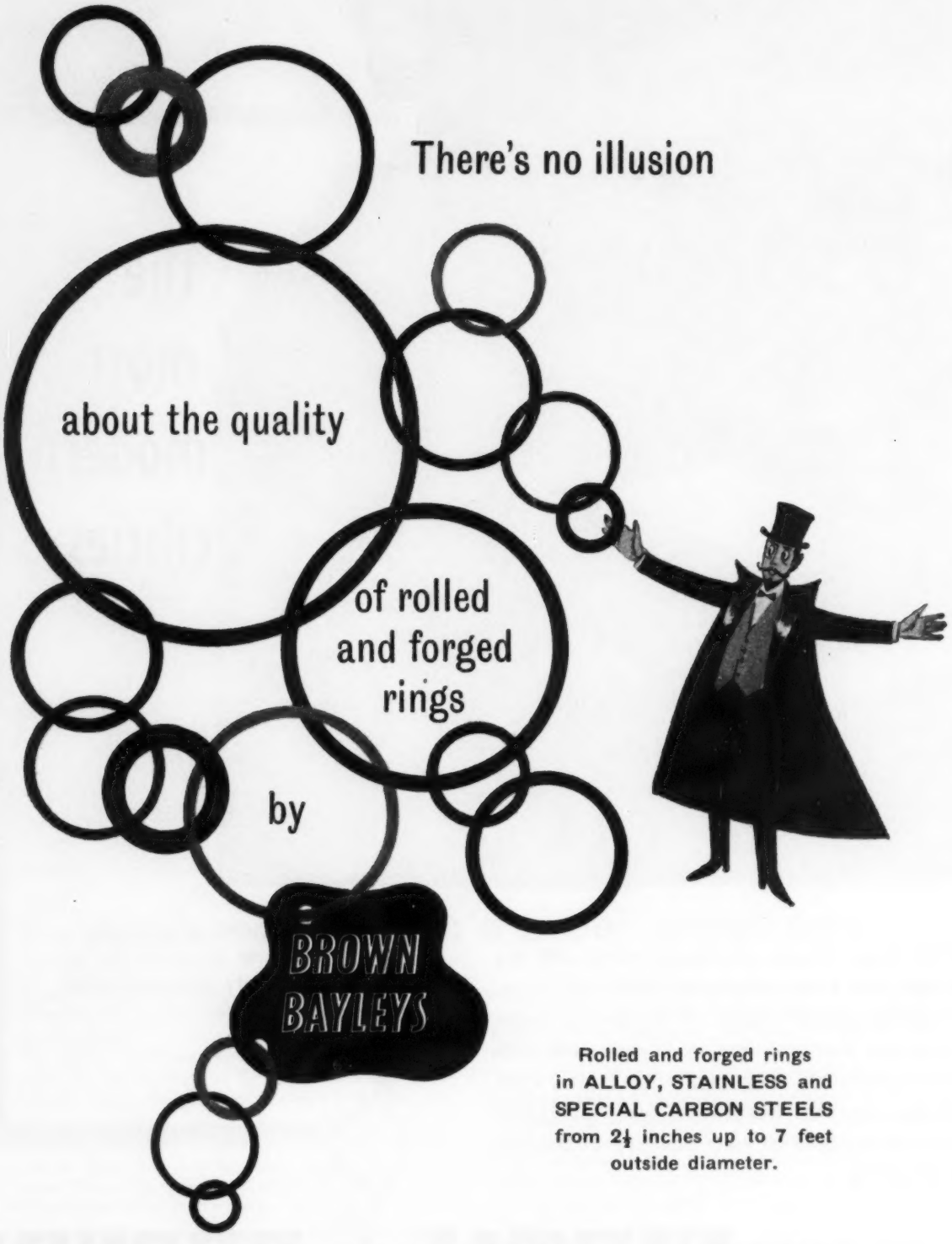


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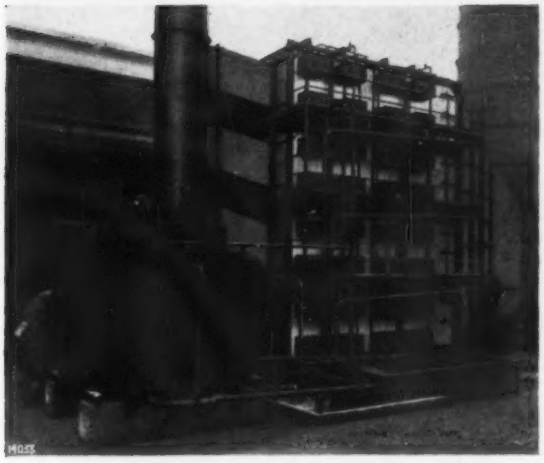

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**PRECIPITATOR**

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*and this is the stack discharge*

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*Publication S7018 giving particulars of Sturtevant Electrostatic Precipitation will be sent on request.*

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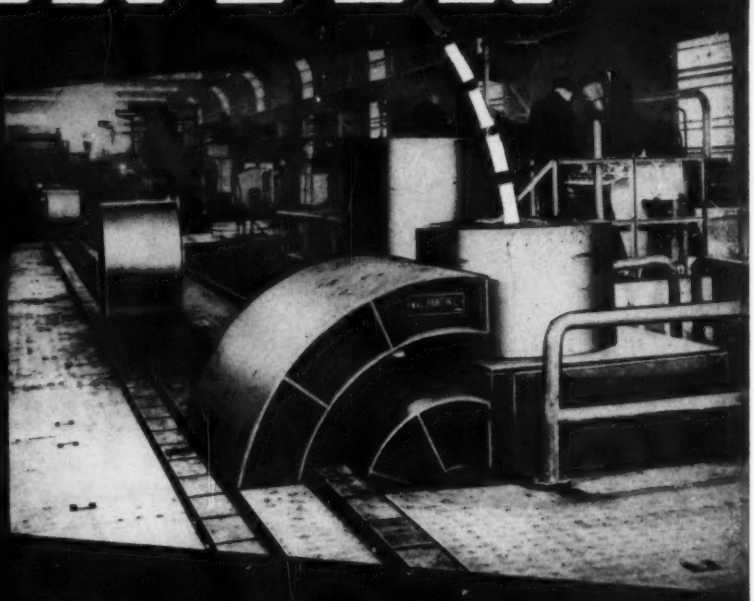

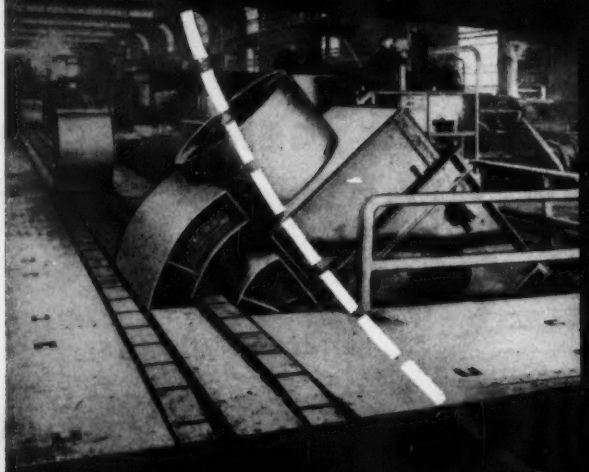

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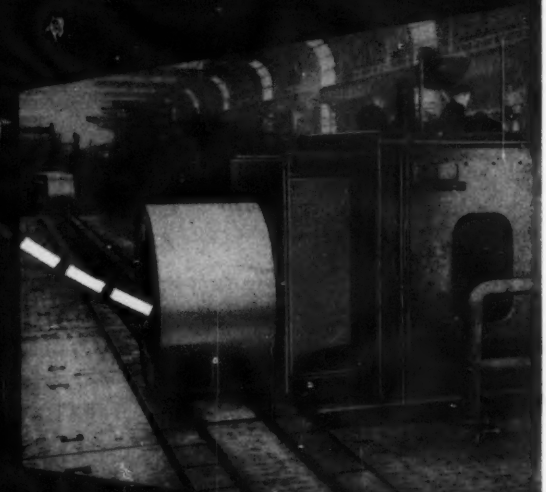

Pantin Handling Equipment covers every requirement, including upending and down-ending, tilting, hoisting and conveying of coils and sheets.

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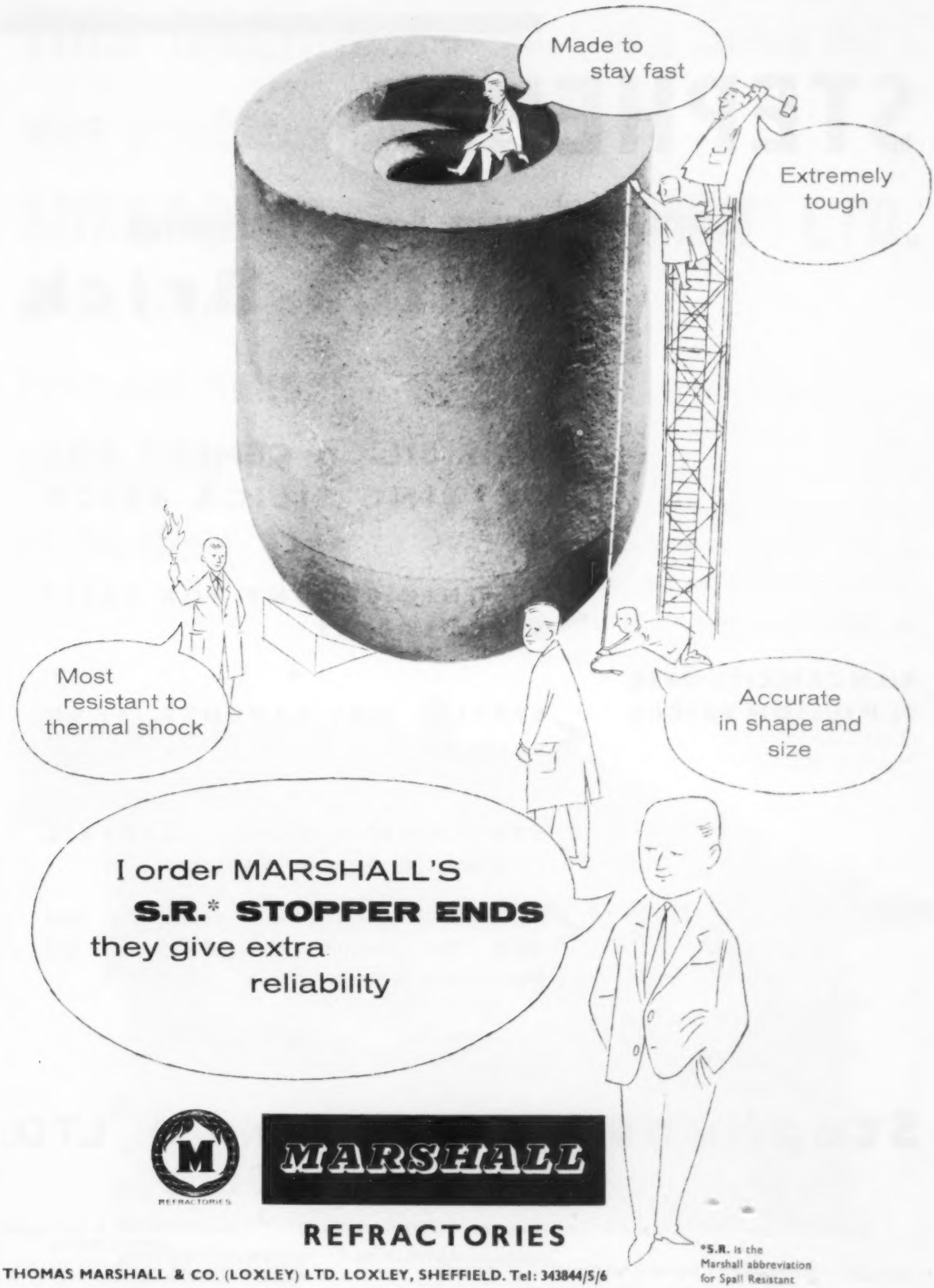


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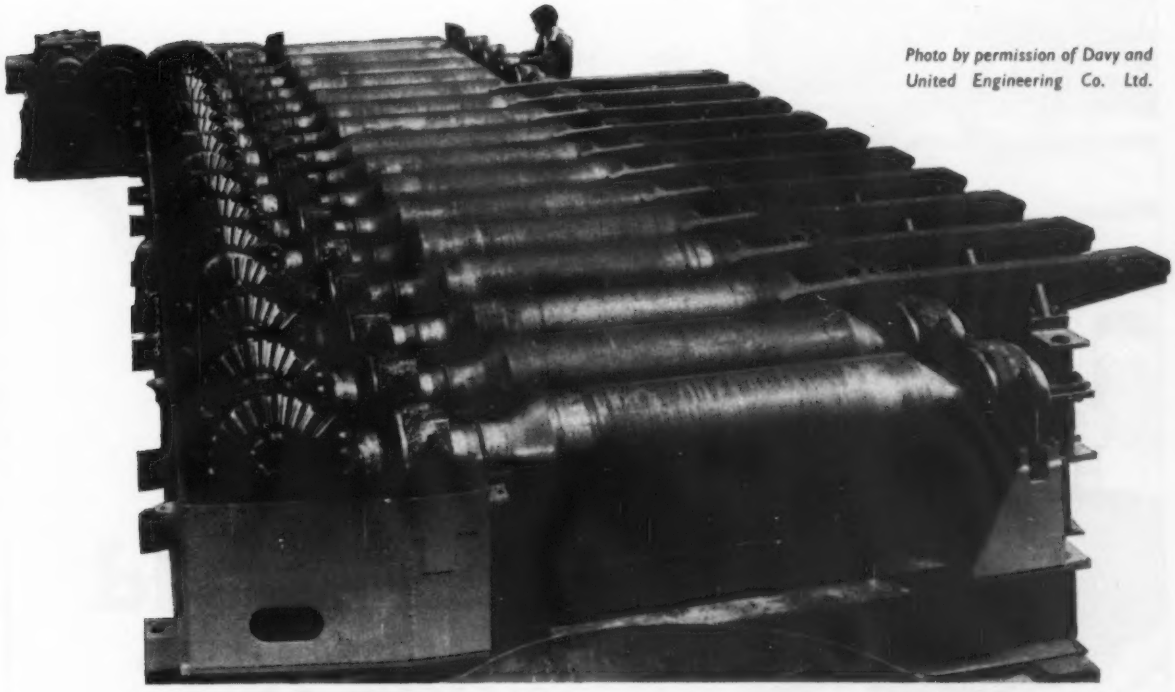

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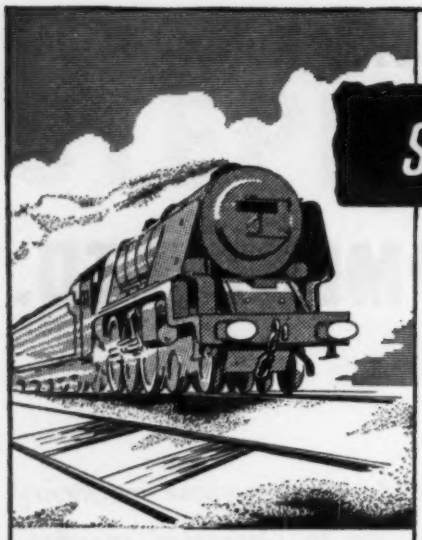

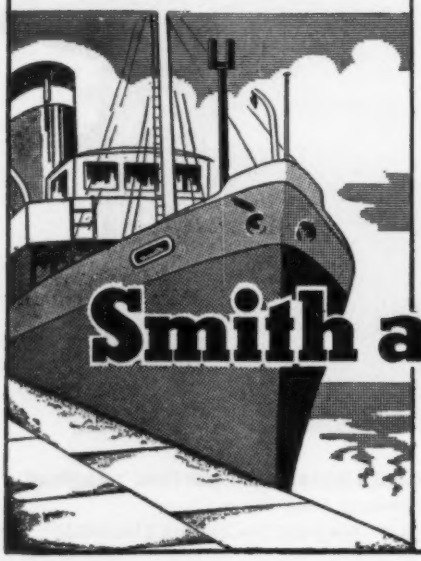

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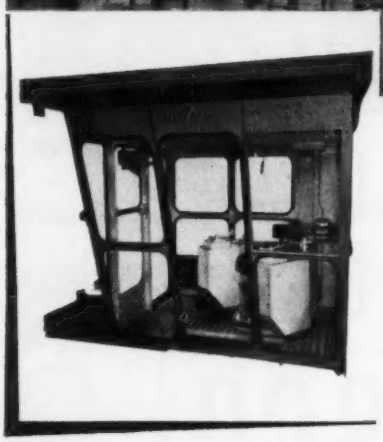

★ *a view of the cab showing the seat control unit.*

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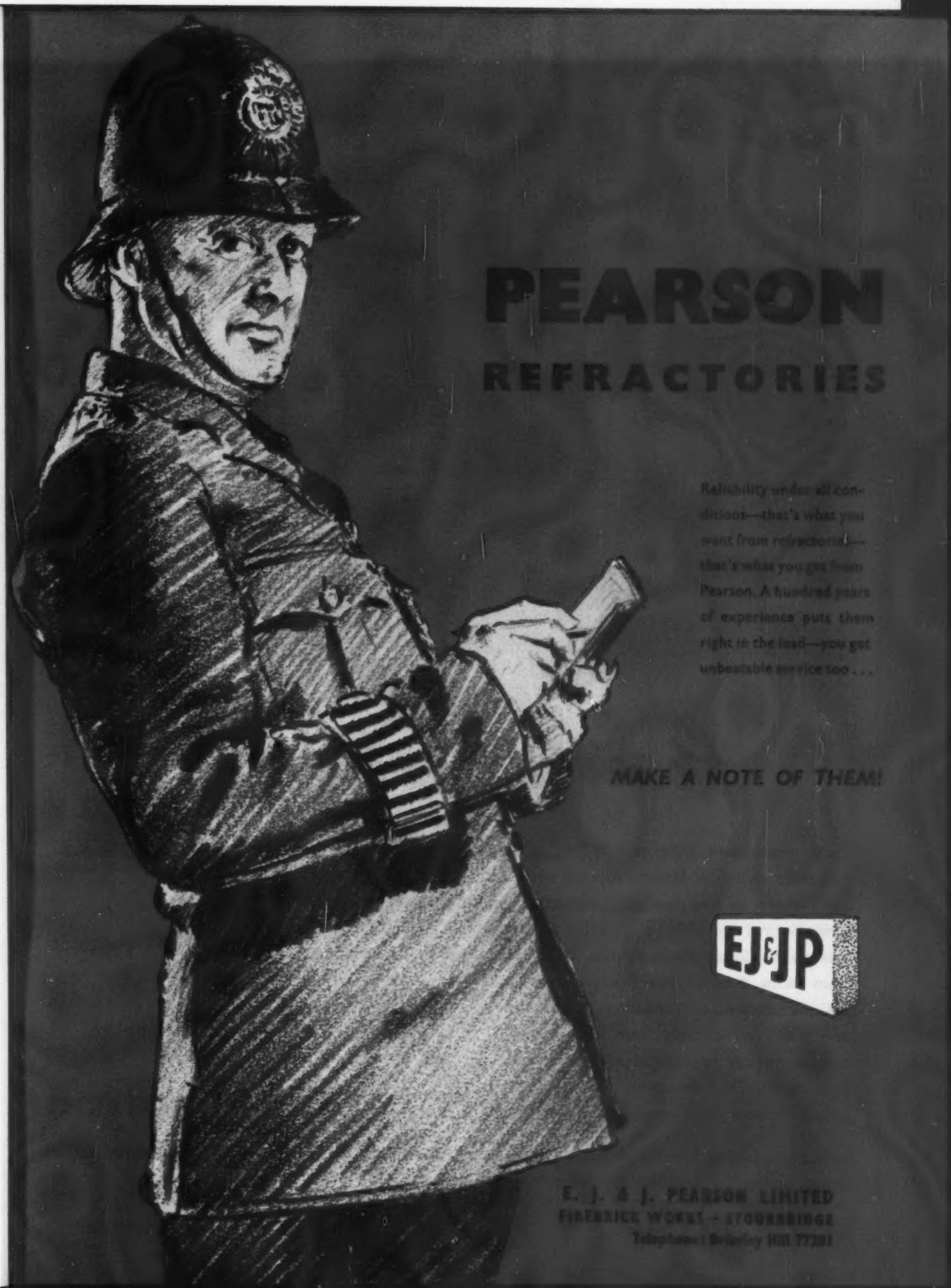
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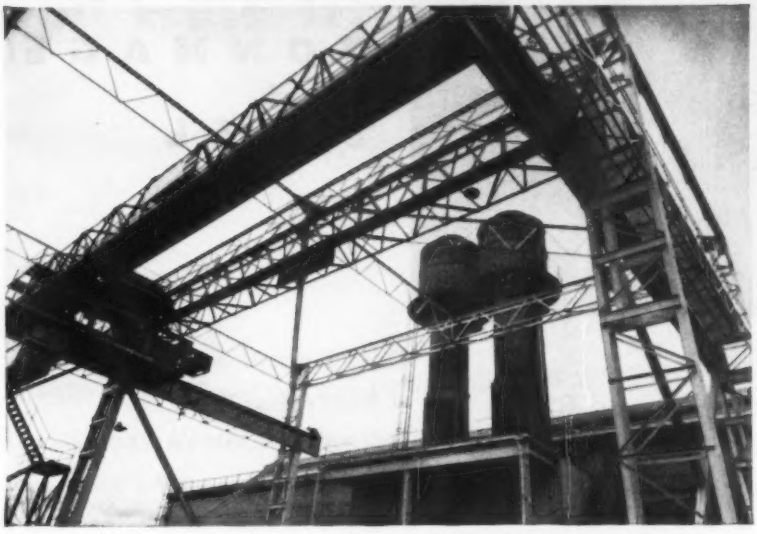

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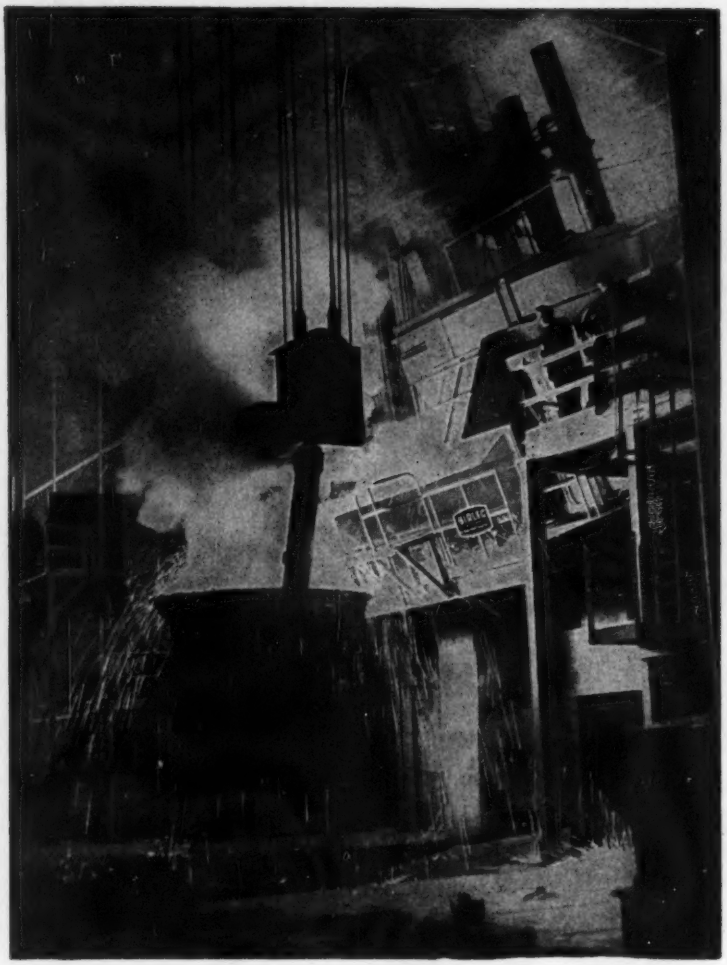

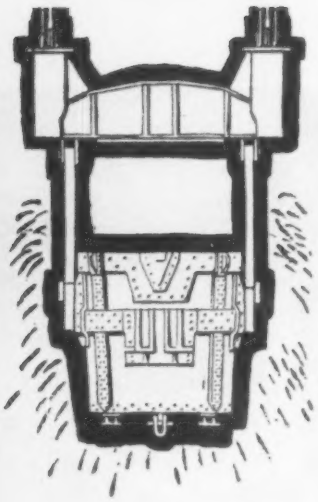

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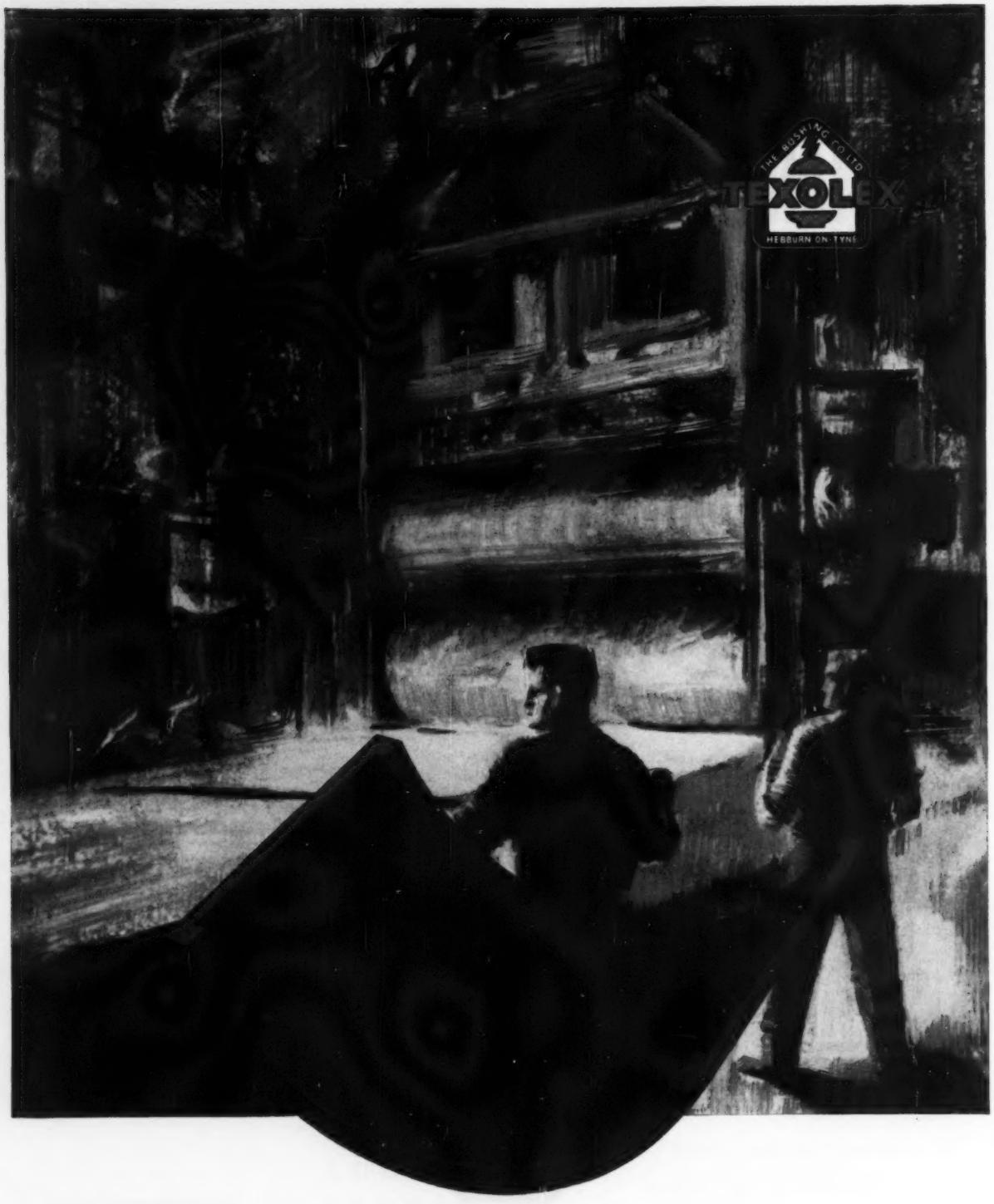


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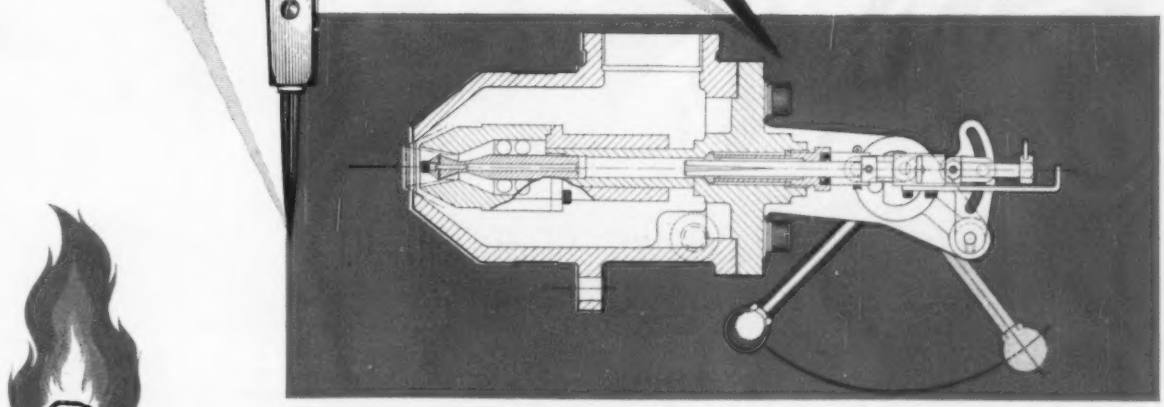

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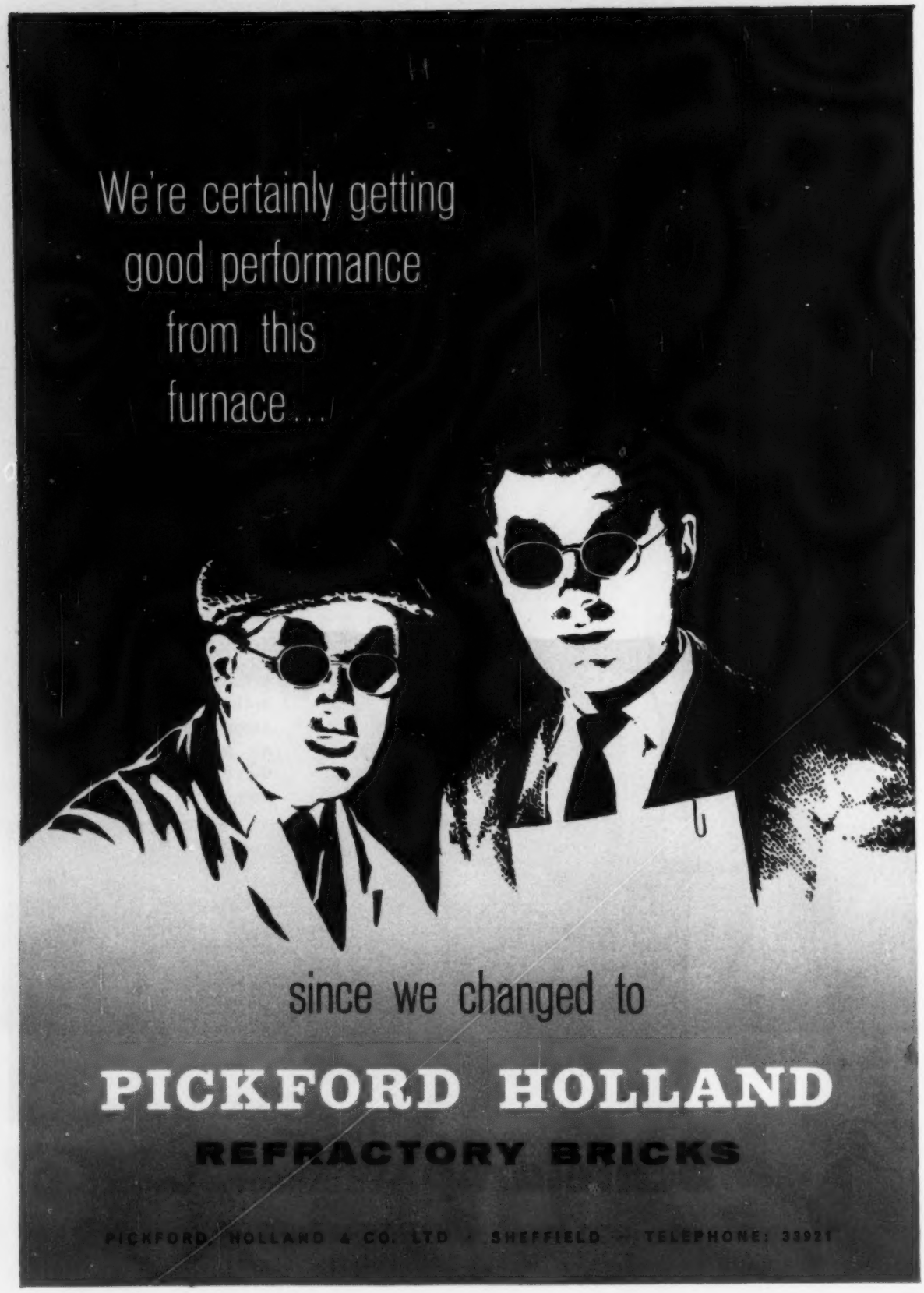
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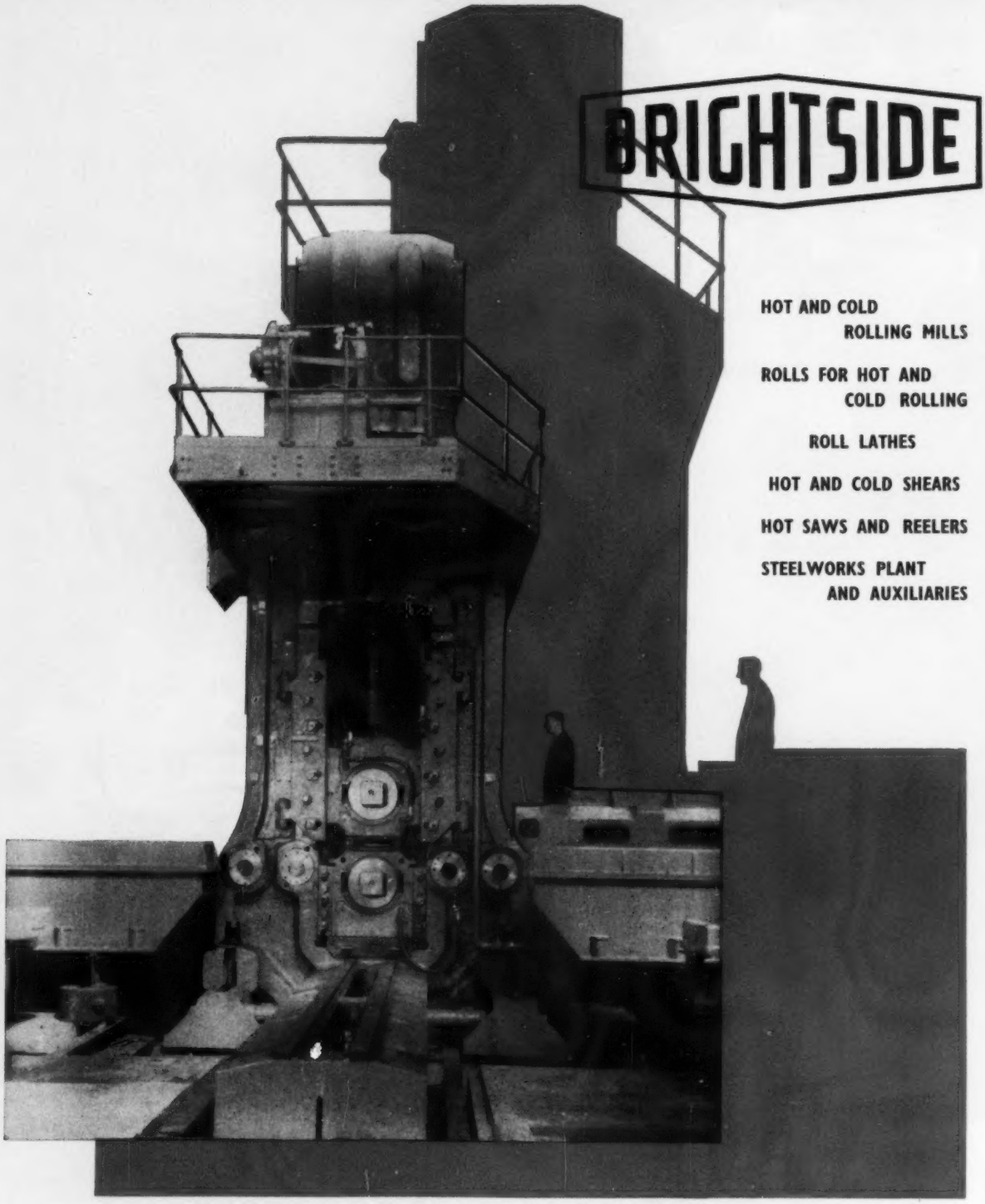


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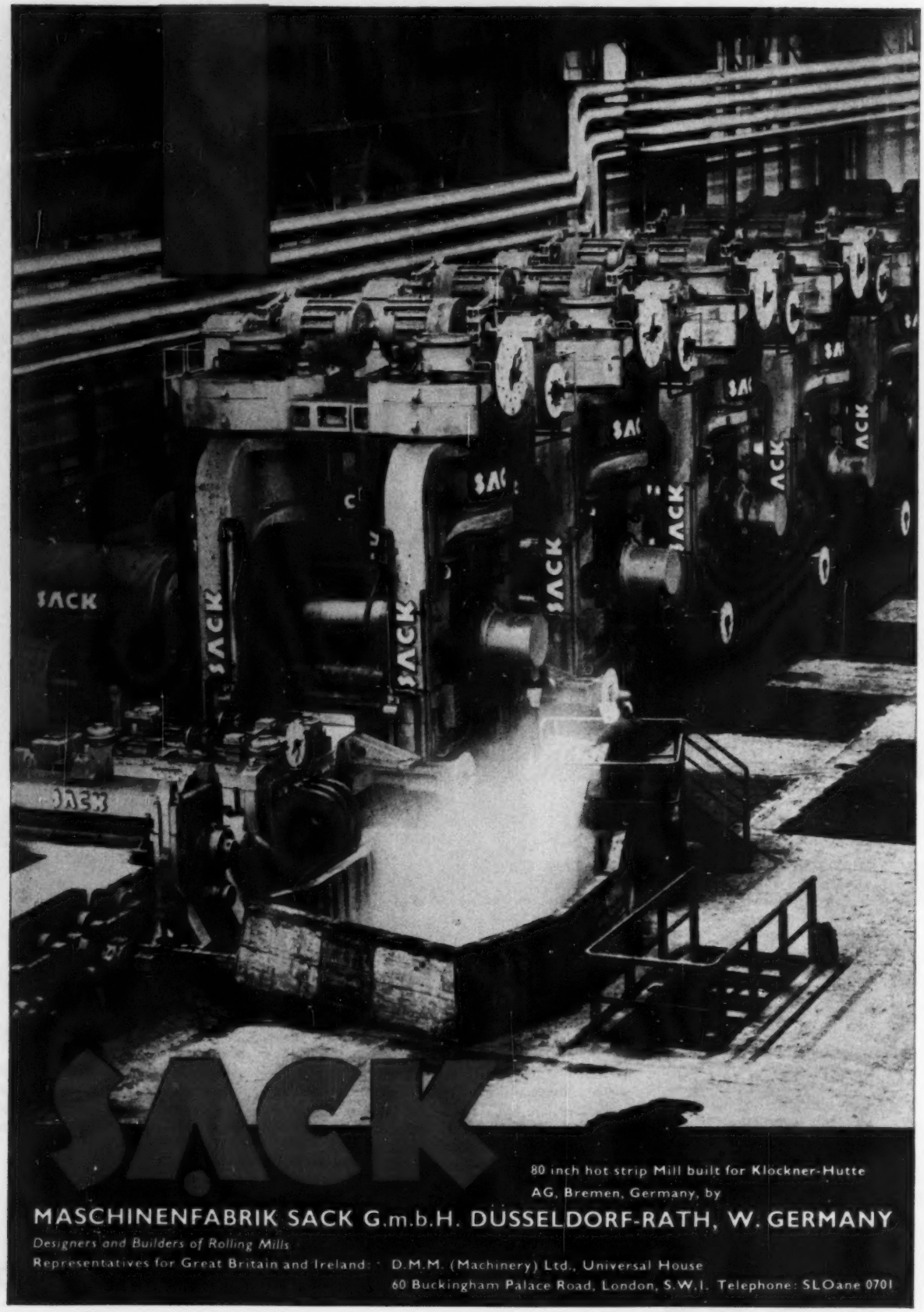


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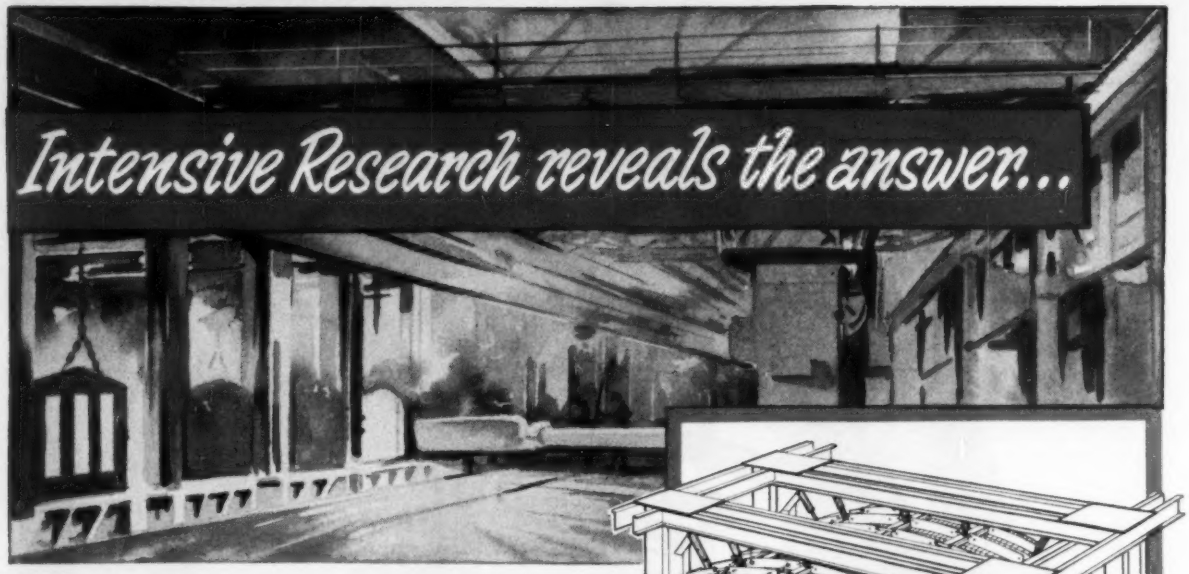


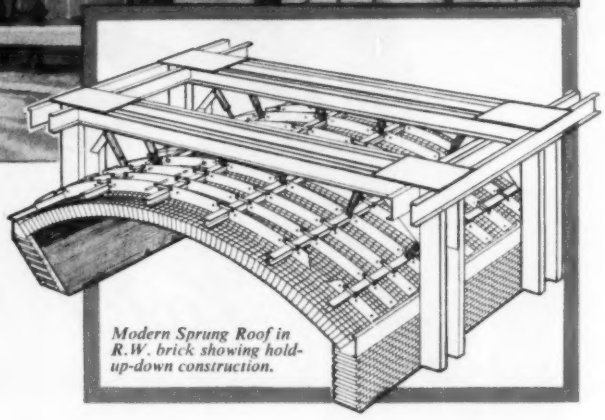

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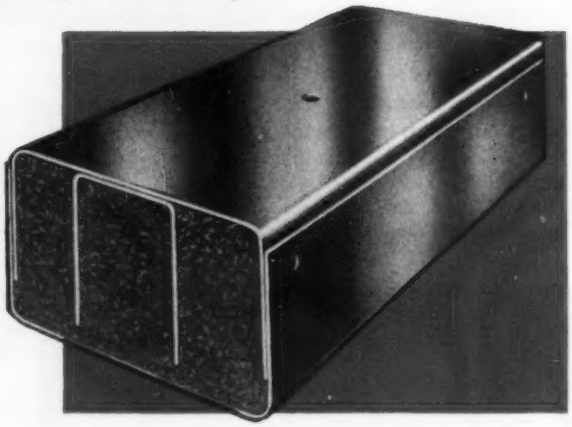

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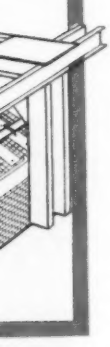

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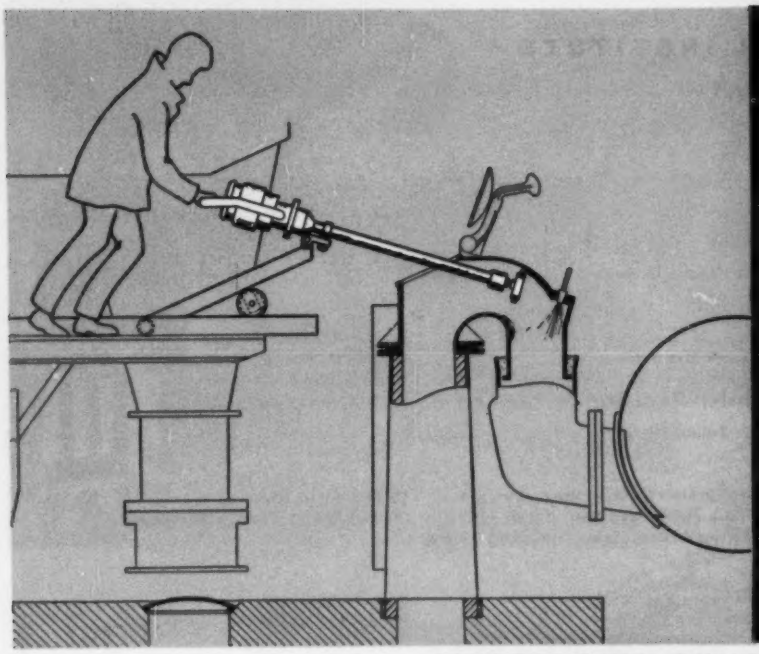

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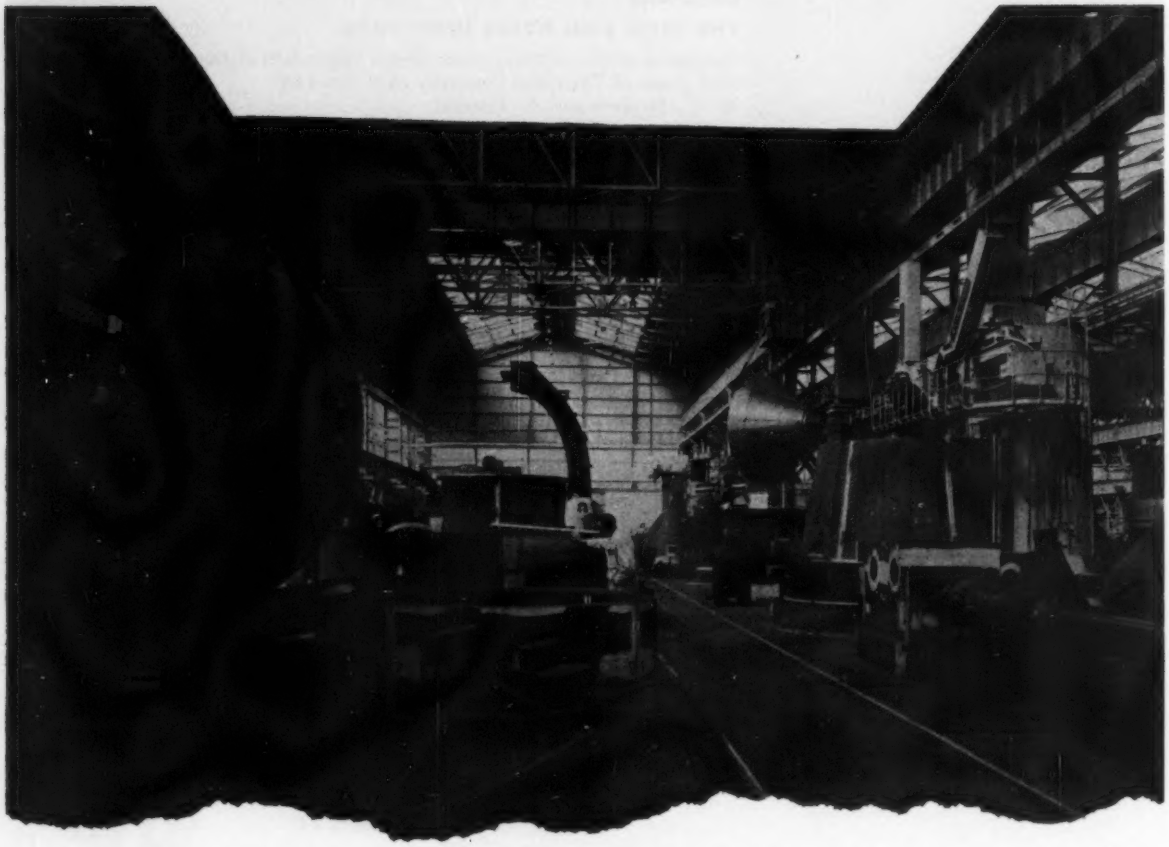

Heavy machine bay in the Stockton workshops. Total floor area of the machine and fitting areas is over 160,000 sq. ft.

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**J. W. TODD, F.I.M.**

JOHN WILLIAM TODD was born in Coatbridge, Lanarkshire, in 1908. He was educated at Coatbridge Secondary School, and acquired his technical education by part-time study at Coatbridge Technical College and at The Royal College of Science and Technology, Glasgow. In 1925 he joined Stewarts and Lloyds as an analytical chemist, and in 1934 he transferred to that company's research department at Corby. During the war period 1939 to 1944 he was engaged in the development of shell forging plants and the production of armour-piercing shot. He was personal assistant to the director of steelworks development from 1944 until 1947 when he was appointed works manager of the Clydesdale Steel and Tube Works. In 1951 he was appointed assistant general manager of this branch of Stewarts and Lloyds.
Mr Todd has been a member of the Standing Committee of The Iron and Steel Trades Employers' Association since 1950, and was appointed Chairman of its Scottish Division in 1960. In 1952 he became a Fellow of The Institution of Metallurgists. He joined The Iron and Steel Institute in 1937 and was President of the West of Scotland Iron and Steel Institute from 1959 to May 1961, during which time he served as an Honorary Member of Council of The Iron and Steel Institute.

**J. W. Todd, F.I.M.**

*Honorary Member of Council, 1959–1961*

# Operation of the oxygen/steam blown converters at the VLN steel plant of The Steel Company of Wales Ltd

*M. C. Harrison, A.I.M., and P. Truscott, B.Sc.*

**SYNOPSIS**

*The VLN converter plant at the Abbey Works of the Steel Company of Wales Ltd, is unique in that it is the only bottom-blown converter shop in operation which has no air blower, the blast consisting entirely of a mixture of oxygen and steam. The paper describes the layout of the plant, the method adopted for lining the converter, and the manufacture of bottoms. The use of high-phosphorus iron necessitates a double-slag process in order to ensure a steel analysis suitable for the most severe deep-drawing purposes, this grade of steel being the main product of the plant. The use of oxygen/steam blast results in an exceptionally low nitrogen content (averaging 0·001%) which has a marked effect on reducing the rate of ageing.* 1979

## INTRODUCTION

THE INCREASE IN MILL OUTPUT which was expected as a result of the changeover to the universal mill at the Abbey Works necessitated an increased ingot output of about 12000 tons per week. It was essential that this steel should be of the highest quality and suitable for all deep-drawing purposes. The availability of tonnage oxygen and the low conversion costs inherent in the pneumatic processes, together with the lower capital costs involved in the construction of new plant, made some type of pneumatic process an attractive proposition. At the same time, the favourable supply position with regard to high-phosphorus ores, and the fact that the open-hearth shops could deal with all the scrap available and the quality of steel required, in particular the very low level of N attainable, led to the choice of the bottom-blown oxygen/steam process. This process has been successfully developed by Centre Nationale des Recherches Mètallurgiques at Esperance Longdoz and Klöckner AG at Hagen Haspe.

Apart from the problems always associated with the starting up of a new plant, the commissioning of the VLN steelplant at the Abbey Works presented a number of completely new problems, since the plant is unique in so far as it is the only bottom-blown converter shop in operation which has no blower capable of operating the converters by air and thus relies entirely on mixed steam and oxygen blast. Experience was available regarding the quality of steel produced by this method, but generally speaking it was only employed in the manufacture of comparatively small quantities of steel required for deep-drawing purposes. Thus actual operational experience in the production of large tonnages on a continuous basis was non-existent.

Where this blast has been employed it is usual, in order to improve bottom life and ensure safe operation, to run the first few casts of a new bottom with air and also to blow both the first part of the charge and frequently the afterblow with air or oxygen-enriched air. Since this was impossible the two major problems anticipated, therefore, were:

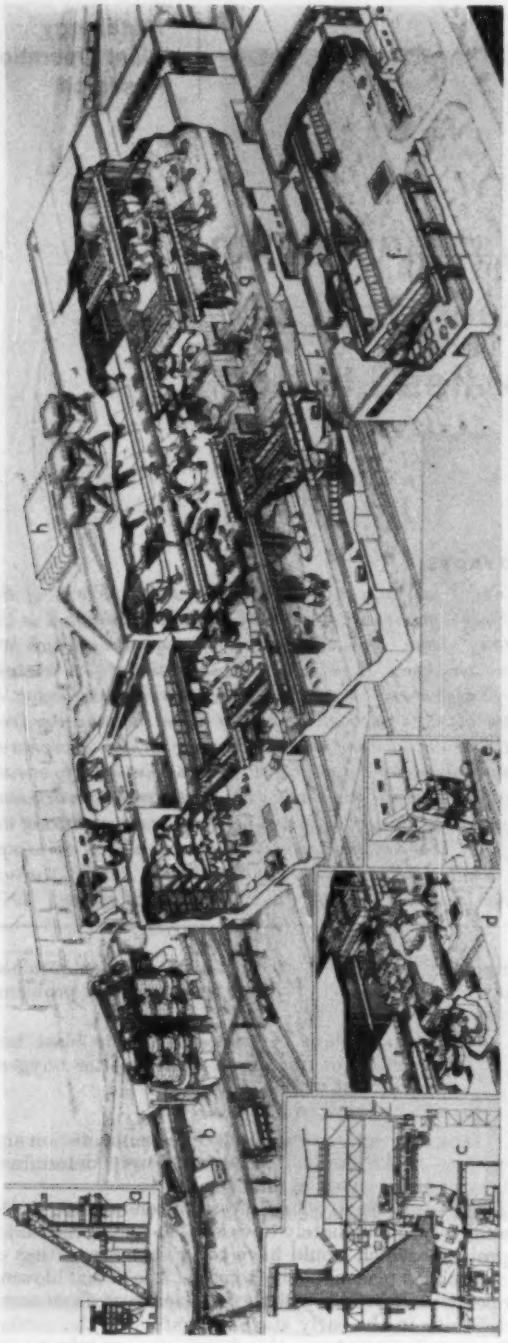
(i) the possibility of explosion in the blast box which might arise from mixing of the oxygen/steam blast with tar vapour
(ii) the bottom and lining life.

The design and arrangement of instrumentation and control of the method of blowing were determined bearing these points in mind.

The plant began operations at the end of June 1959, and it was immediately obvious that one of the major problems which would have to be solved was that of obtaining a reasonable bottom life. The actual blowing operations gave very little trouble apart from some difficulty in the early stages in obtaining the correct tapping temperature, this being due mainly to inexperience and the fact that small charges were being blown. The quality of steel produced has been very satisfactory throughout, being at least as good as, and in some respects better than, that produced from our OH shops. Once the problem of bottom life had been solved, it became apparent that there would be little difficulty in reaching the desired output of 12000 tons per week.

It is not intended in this paper to discuss aspects of

Manuscript received 10 April 1961.
Mr Harrison is manager, and Mr Truscott assistant manager of the VLN steel plant of The Steel Company of Wales Ltd.




1 *VLN plant, Abbey Works, The Steel Company of Wales Ltd*

steelmaking such as the casting bay and mixer furnaces, which are normal to most steelmaking processes, but rather to concentrate on those aspects which are peculiar to a steam/oxygen blast in bottom-blown converters. The following is a brief description of the VLN steel plant at the Abbey Works, The Steel Company of Wales Ltd.

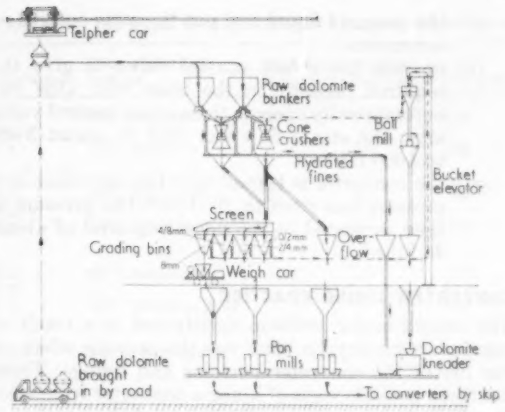
## GENERAL LAYOUT OF THE PLANT

The plant (Fig.1) is on the west side of the Abbey Works and is completely self-contained, having its own mould bay and lime plant separate from those units servicing the OH melting shops. The lime plant, which is situated on the seaward side of the VLN steel plant, comprises four kilns 60 ft high × 12 ft dia. each of which is capable of producing about 3 tons/h of burnt lime, with a consumption of about 50 therms/ton of mixed coke-oven and blast-furnace gas. Load cells are attached to the discharge hoppers in order to give an exact weight of the lime drawn. Lime is fed through a screening tower to four 300-ton holding bunkers. These bunkers discharge into skips working on a monorail system which transfer the lime to the top floor of the main VLN steel plant building where they empty into weigh hoppers situated directly above the converters.

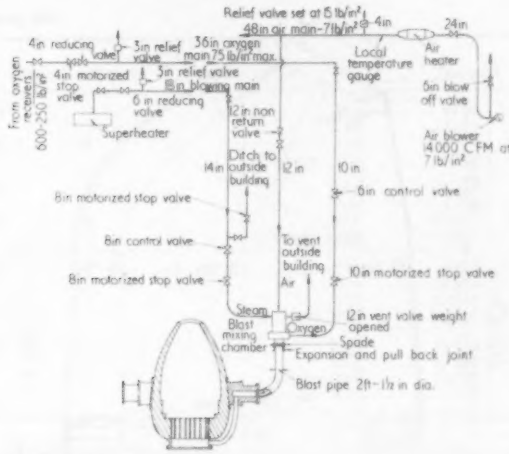
At the north end of the converter bay there are two 1250-ton mixers which are supplied with metal in Kling ladles from the blast-furnace plant. The metal is poured into the mixers by means of a 135-ton crane. These mixers have a magnesite working lining; only one mixer has so far been put out for repair, the throughput being 411000 tons. The mixers discharge on the opposite side into transfer ladles carried by a 100-ton crane, which pours the metal into one of three 60-ton converters. Space is allowed for a fourth converter. This bay also has two 15-ton magnet cranes for the supply of scrap and any other materials required, these being stored at the south end.

The converters pour into ladles which are mounted on a carriage. This carriage transfers the teeming ladles from the converter bay to the casting bay where they are picked up by one of two 100-ton cranes for teeming. There are eight teeming platforms each of which is capable of taking one charge. The full trains are normally handled in pairs, thus constituting 100 to 120 tons a shunt. Full ingot trains are transferred to the stripper bay while empty trains are shunted into the mould bay, where they are berthed in one of two platforms each of which will take a double train for cleaning and setting the moulds.

The dolomite shop where the preparation of material for linings and bottoms is carried out is situated at the south end of the main building, and is served by a 40-ton overhead crane. Dolomite is received by lorry in special containers which are berthed underneath a 12-ton pendant-operated crane which lifts them to the top of the dolomite tower (Fig.2). The dolomite is then discharged into one of two 80-ton hoppers which feed into two cone crushers, hydrated material being screened out during the transfer. The cone crushers feed onto a Gyrex screen which discharges the material into a series of grading bunkers. The overflow from these bunkers is returned by means of a bucket elevator to a small hopper situated at the top level of the tower; from here the material can either be re-circulated into the system via the crushers, or fed into a




2 *Diagrammatic layout of dolomite tower*




3 *Oxygen/steam supply system*

ball mill which reduces the dolomite to powder; this is stored in another grading bunker for use as bottom jointing material.

The grading bunkers discharge into an electrically-operated weigh car which collects the required amount of each size and then feeds it to one of three steam-heated pan mills, where the dolomite is mixed with the required amount of tar. In addition to the three pan mills there is a dolomite kneader, where the fine dolomite is mixed with a high percentage of tar in order to make the bottom jointing material. Also situated in the dolomite house is a vibrating machine for consolidation of the converter bottoms, and three blast-furnace gas-fired bottom heating ovens in which the manufactured bottoms are heated, in order to coke the tar, before use in the converters.

## OXYGEN/STEAM SUPPLY

The layout of the system and method of control have been described by Fletcher and Pullen[1] and are shown in Fig.3. Oxygen is received from the British Oxygen Company and is stored in four receivers with a total capacity of approximately 274000 ft³ at a maximum pressure of 600 lb/in². In order to satisfy the intermittent demands from the VLN steelplant a 4-in flow control valve is situated in the supply line. This regulates the flow into the receivers giving a fixed flow over the hour equal to the total demand of the plant. The receivers discharge into an 18-in dia. line through an 18-in stop valve, and finally to a 4-in stop valve followed by a 4-in pressure-reducing valve. This lowers the oxygen to the required pressure of 75 lb/in² at which level it is held in the 36-in blowing main which follows the reducing valve. In case of failure of the reducing valve this main contains a loaded relief valve set at 84 lb/in². From the 36-in main a 10-in branch leads off to each converter; this line contains a flow-measuring orifice plate, a 6-in control valve, a 10-in stop valve, and then leads into a blast-mixing chamber where it meets the steam supply.

The steam supply is received from the works main at about 150 lb/in² pressure and at a temperature of 230–250°C. It is superheated to 350°C by means of a blast-furnace gas-fired superheater. The superheater discharges into a 10-in steam main and then through a 5-in stainless-steel reducing valve which reduces the pressure to 75 lb/in² in an 18-in blowing main. From this main a 14-in branch is taken to each converter; this line leads through a control valve and stop valve to the blast-mixing chamber. In this line is also situated an 8-in ditching valve through which steam can be passed before starting operations to warm up the system.

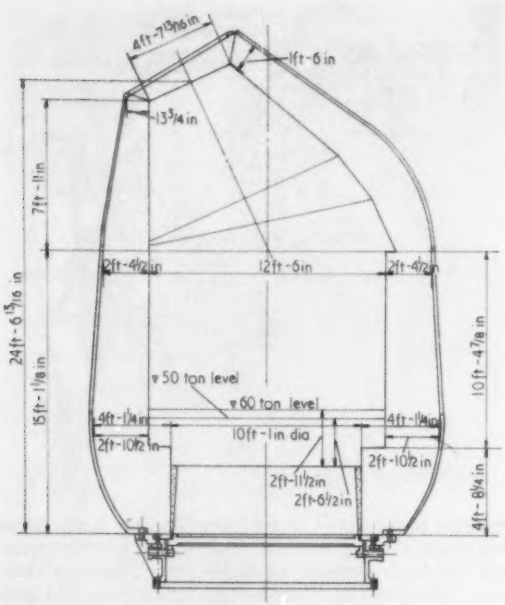
### Converter instrumentation

Adjacent to each converter is the control room which contains all the instruments and controls necessary for operation of the converter. The instruments are as follows: a steam flow indicator–recorder; oxygen flow indicator–recorder; steam temperature indicator–recorder; oxygen temperature indicator–recorder; mixed blast temperature indicator–recorder; oxygen pressure indicator (storage vessels); oxygen pressure indicator (blowing main); oxygen/steam ratio indicator (by volume); steel temperature indicator–recorder; lime weight indicator (weigh hopper above converter); stop clock; steam ditching-valve position indicator.

Alarm signals on the converter panel are shown by means of lights:

(i) low oxygen storage pressure
(ii) oxygen and steam control valves fully shut
(iii) stand-by Askania regulator oil pump running
(iv) total failure of Askania oil pumps
(v) hydraulic pressure.

On the desk below the panel are pushbutton controls operating all the stop valves and also the Askania regulators which control the oxygen and steam flows. The oxygen/steam ratio can be varied either automatically or manually; in the former case the steam flow governs the oxygen and in the latter both are adjusted independently. The chief hazard expected to be encountered was the possible danger that might arise should there be tar vapour present in the blast box. It was considered that in the event of an oxygen-rich mixture being used, there might be danger of a serious explosion taking place. To obviate the danger of such an explosion, a number of further precautions were taken, the major one being arrangements for flushing out the blast box by means of air before blowing begins.




**4** *Cross-section through converter showing lining*

As stated earlier no blower capable of working a heat had been installed; a small one capable of supplying 14000 ft³/min at 7 lb pressure had, however, been sited in the hydraulic house for the purpose of supplying air for burning in converter linings. This blower was connected into the blowing main by means of a stop valve and a non-return valve. This latter valve shuts automatically against the air supply when the steam/oxygen blast pressure exceeds 7 lb. In addition there is a vent just short of the steam/oxygen mixing chamber controlled by a clack valve operating at 2 lb/in² pressure. If there is a slight leak through the oxygen or steam control and stop valves when not blowing, the clack valve will open and bleed to atmosphere, closing again as soon as the air or oxygen/steam blast is turned on. In addition to these precautions a slight bias is given to the steam to ensure that it always enters the blast box before the oxygen.

Before the plant started, a standard sequence of operations for working the converter was laid down, and this is adhered to under all normal conditions. Only one major modification had to be made to the standard and this related to pressure control. It had been anticipated that the converters would operate on automatic control of both pressure and ratio. It was, therefore, intended to set the pressure at a given figure and allow the steam and oxygen flows to vary at a set ratio. In practice it was found that this caused considerable hunting between the steam and oxygen supplies. As a result the blast pressure is now controlled manually, and the ratios automatically. The method of starting the blow operation, therefore, is:

(i) open the air stop valve, thus allowing the air to enter the blast box through the non-return valve
(ii) open the steam stop valve
(iii) open the oxygen stop valve
(iv) set the automatic oxygen/steam ratio control at the required figure and put the ratio control on automatic
(v) operate the steam control valve to give the required pressure in the blast box. This will automatically operate the oxygen control valve after the steam flow has risen to about 3000 to 4000 ft³/min
(vi) the converter is turned up when the blast-box pressure has risen to 20 lb/in²; the pressure is then increased to the operating level of about 35 lb/in².

## CONVERTER LINING PRACTICE

The second major problem anticipated as a result of using a steam/oxygen blast was the possible effect on the life of the converter bottoms and linings. There are three possible ways of lining a converter which can be adopted, or varying combinations of these three:

(i) bricking with fired or unfired bricks
(ii) the use of shaped blocks which are hydraulically pressed, usually within the works, composed of a refractory material with a tar bond
(iii) the lining can be completely rammed with a similar material.

For various reasons it was decided to adopt the third method and the first linings were rammed using a mixture of tar and dolomite of the following grading:

| 0–0·5 mm | 0–2 mm | 2–4 mm | 4–8 mm | >8 mm |
|---|---|---|---|---|
| 25% | 10% | 15% | 25% | 25% |

The procedure for installing the lining is as follows. A steel ring is first placed inside the blast box and secured by means of pins in the same manner as the actual bottom plate required for blowing is fixed. On top of this ring the first course of shuttering is fixed, consisting of a series of light steel plate sections curved to suit the diameter required. The plates can be fitted to one another by pins and cotters. When each plate ring has been fitted, the tar/dolomite material is fed in from the top of the converter by conveyor and chute to give a level depth of about 6in and then compacted by pneumatic rammer. The first two courses, covering a height of 4 ft 8in give a maximum thickness of 4 ft 1in in order to compensate for the very heavy wear which takes place in this area owing to the turbulence of the metal when blowing (Fig.4). After the second course the lining is stepped back about 15in and the procedure is then quite straightforward until the hood section is reached, the various steps being fitted and rammed by the men who work from a hydraulically operated repair platform fixed to the converter blast box. The height of this platform can be adjusted to suit the working level within the converter. The first section of the hood can still be rammed with the converter in the vertical position, but after this it is necessary to erect scaffolding on top of the repair platform and to tilt the converter in order to allow the ramming to be completed. All sections of shuttering in this area must be suitably numbered, as it is essential that they are put in correctly in order to obtain the required contour. As soon as the ramming has been completed the shuttering is removed and the converter made ready for lighting.

The original method for burning in the lining was the conventional method adopted on the majority of bottom-blown plants, namely the use of coke fires. This appears to work fairly successfully in plants

**TABLE I The effect of composition of ramming materials on lining life**

| Converter | Composition of bottom | %MgO in magnesite | Grading, % 0–0·5 mm | 0–2 mm | 2–4 mm | 4–8 mm | 8+ mm | Lives | | Tonnage |
|---|---|---|---|---|---|---|---|---|---|---|
| A.4 | 20% magnesite | 90 | 40 | 30 | 30 | ... | ... | | 172 | 9989 |
| B.3 | ... | ... | ... | ... | ... | ... | ... | | 196 | 11298 |
| C.4 | 80% dolomite | ... | 25 | 30 | 15 | 30 | ... | | 139 | 7913 |
| | | | | | | | | Average | 169 | 9733 |
| A.5 | 50% magnesite | 90 | 40 | 30 | 30 | ... | ... | | 165 | 9185 |
| B.4 | ... | ... | ... | ... | ... | ... | ... | | 148 | 8504 |
| C.5 | 50% dolomite | ... | 25 | 30 | 15 | 30 | ... | | 217 | 12422 |
| | | | | | | | | Average | 176 | 10037 |
| A.8 | 85% magnesite | 72 | 19 | 17 | 15 | 38 | 11 | | 212 | 12648 |
| B.7 | ... | ... | ... | ... | ... | ... | ... | | 180 | 10869 |
| C.7 | 15% dolomite fines | ... | ... | 100 | ... | ... | ... | | 195 | 11930 |
| | | | | | | | | Average | 196 | 11816 |
| A.9 | 100% dolomite | ... | 25 | 30 | 15 | 30 | ... | | 212 | 12275 |
| B.8 | ... | ... | ... | ... | ... | ... | ... | | 212 | 12985 |
| C.8 | ... | ... | ... | ... | ... | ... | ... | | 211 | 13056 |
| | | | | | | | | Average | 212 | 12772 |

where converters are lined with bricks or pressed refractory blocks, although even in such plants failure of the lining during firing is by no means unknown. It was anticipated that our method of ramming the lining might give rise to some difficulty during the burning-in period and these fears were proved correct. In spite of getting a very intensive fire burning in the shortest possible time, a number of linings collapsed within the first few hours of lighting up. It was decided that a more satisfactory method must be found. As a result a burner using coke-oven gas at the rate of 50000 ft³/h was designed to fit on the blast box flange. This has been most successful and no difficulties are now experienced in what used to be a very doubtful operation.

Normal lining life in the early days was about 120–140 heats, after which heavy localized wear in the horizontal slag line and lower section of the converter belly necessitated putting the converter off. This comparatively short life meant that certain of the remaining areas were very thick and considerable difficulties were experienced in demolition, since the rammed mixture had formed a complete monolith. It was, therefore, necessary that the lining life should be prolonged and, if possible, the time of demolition reduced. Considerable experimentation was carried out to find the most suitable grading of material for ramming. The final figures decided upon and which is now in use is:

| 0–0·5 mm | 0–2 mm | 2–4 mm | 4–8 mm |
|---|---|---|---|
| 25% | 30% | 15% | 30% with 8% tar |

It was also thought that the use of magnesite in place of dolomite, particularly in those areas subject to heavy wear, would have a beneficial effect. This material was added to the ramming mixture in varying percentages and used in those areas which experienced heavy wear. In addition a number of linings were rammed using material containing about 70%MgO throughout the lining except in the roof section of the hood where wear is negligible (Table I). During operation, wear on the magnesite lining appeared normal up to 80–100 heats, but after this it became very rapid.

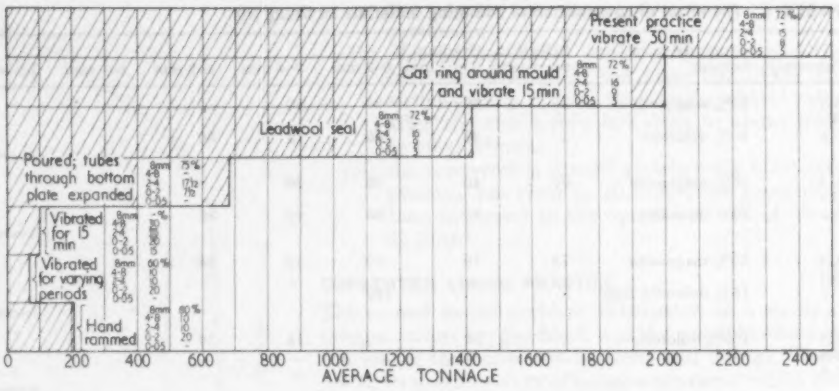
As can be seen from the results, while the magnesite gave a considerable increase over our early operating days, these figures are not comparable with the results being obtained from straight dolomite mixture and the cost ruled out the use of magnesite. The lack of success of this experiment was undoubtedly due to the intermittent operation which is unavoidable on bottom-blown converters and resulted in heavy peeling of the lining when restarting blowing after a bottom change or after blocking tuyeres. As a result of these experiments further use of magnesite was discontinued for a time. Recently a further number of linings using various percentages of magnesite have been rammed. These have shown some improvement over the earlier trials, but the results are still below those obtained by using straight dolomite.

Another step taken has been to offset the shuttering in order to increase the thickness of material in the most heavily attacked areas: this decreases the thickness in the areas of least wear, thus aiding demolition. As a result of the various steps, average lining life is now running at about 230–240 heats, the maximum life being 273 heats giving over 17000 tons on the lining.

Demolition speed has been considerably improved by the use of more suitable tools, the eccentricity of the shuttering, and the use of a parting layer of clay and graphite, which is pasted on the material left in the converter before ramming begins. This pasting enables the demolition gang to cut away in layers instead of attempting to break up the monolith. The normal time for demolition and relining is approximately 4½ days, to which must be added about 16 h for burning in the lining and for fixing and burning in the bottom. Regular samples of the dolomite supplied are taken for chemical analysis and also for bulk density and loss on ignition tests. The analysis is very consistent running about 55–58%CaO and 33–35%MgO with $SiO_2$ below 3½%. There is, however, some variation in the bulk density. Material with a bulk density of under 2·65 g/ml or with a loss on ignition of over 1·5% is the subject of complaint; on the whole the position from this point of view has improved considerably since regular sampling has been instituted.

## PREPARATION OF CONVERTER BOTTOMS

There are three sizes of bottoms for the converters to speed up the time taken to make the bottom change; thus the first bottom on a new lining will be 9 ft 9¾in dia., the second 9 ft 7½in, and the third 9 ft 5in. This reduction in size enables a new bottom to be installed without cutting away the old joint; this job only has to be done after the third bottom. The thickness of the bottom is 3 ft 10in for all sizes with a taper of 6in on




**5** *The effect of bottom-making practice on steel tonnage per bottom*

the diameter from bottom to top, giving a weight of tar/dolomite mixture varying from about 19 tons on the large size down to 17½ tons on the smallest. It was realized before the plant began that obtaining a satisfactory bottom life would be one of the main problems connected with operation of the plant. From the outset a great deal of effort was put into solving this problem, and the various major stages of development are shown in Fig.5.

Before starting operations the actual method of bottom preparation, i.e. ramming or vibrating was considered, and, in view of the fact that to prevent hydration copper tubes had to be used, which would have made ramming very difficult, it was decided to vibrate. Commissioning difficulties with various items of equipment in the dolomite shop made it necessary to prepare the first 12 bottoms by hand ramming with pneumatic rammers. It was not surprising that the first two bottoms failed after about 11 heats, and the remainder of the hand-rammed ones after 4 or 5. It did, however, cause concern when the first batch of vibrated bottoms gave similar lives.

The difficulties associated with improvement of bottom life proved very formidable. The main problem was the method of sealing copper tuyere tubes to the bottom plate, this being essential to successful operation, when using steam, to prevent hydration of the dolomite. In the early stages the copper tubes were 14 mm outside dia., 12 mm inside dia., and were driven into holes of 13·8 mm in the bottom plate; liquid creosote was then poured on top of the bottom plate to fill the countersunk portions of the holes. It soon became obvious the creosote was of no value and the countersunk portions were filled with a mixture of clay and waterglass. No improvement occurred and a different method of sealing was adopted in which copper tubes were coated with a steam sealing compound, driven into the bottom plate and expanded.

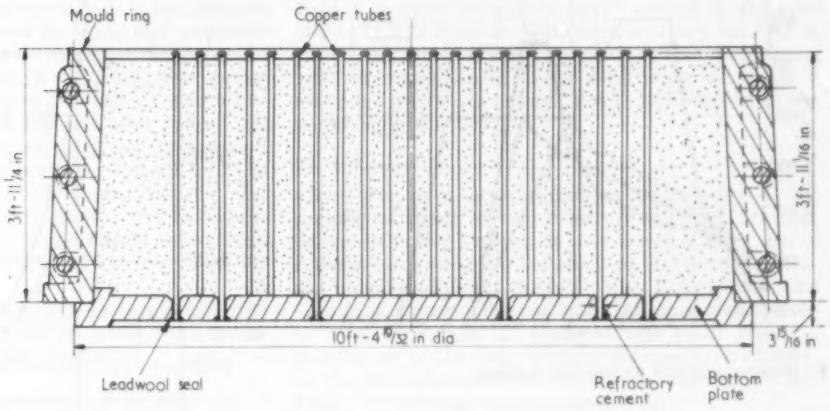
During this period experiments were continuously carried out with different gradings of dolomite, different percentages of tar, variations in vibrating times, and the level of material in the mould at which vibrating begins. Although a good consolidation of material appeared to be obtained there was no improvement in the life of the bottoms. Hydration of the dolomite was still taking place, in many cases resulting in cracking of the 4-in bottom plate, and individual boring of tuyeres was as bad as ever. It was decided to alter completely the method of bottom preparation, both as regards sealing of the copper tubes and the grading and preparation of the tar/dolomite mixture. The size of the copper tubes was reduced to 13½ mm outside dia., and these were passed completely through the bottom plate and then expanded by means of a pneumatic tool into the countersunk section of the underside. The proportion of large material in the dolomite was increased considerably and at the same time suspension of the pan mill rollers was removed thus increasing the load on the material which was dry milled for a period of 10 min before tar was added. The amount of tar in the mix was increased to 13% and the total mixing time lengthened to 30 min, giving an overall time in the pan mill of 40 min. After this treatment the mixture was entirely different in appearance from the earlier type; being very fluid, it could be poured into the mould and allowed to find its own level. Bottoms prepared by this method showed the first signs of improvement and averaged about 16 heats although a considerable amount of time was taken up during blowing in order to block tuyeres which were boring.

A life of 16 heats per bottom was obviously still very unsatisfactory and the cause of failure was, and still is, attributable to one of two factors, both primarily associated with the use of steam/oxygen blast.

(i) the temperature at the face of the bottom due to the high oxygen content of the blast causes a very rapid rate of wear and excessive funnelling

(ii) the method of sealing the copper tubes in the bottom plates, which was, in the early stages of plant operation, the major cause of poor life.

In normal bottom-blown converter operations using air or oxygen-enriched air the danger of dolomite hydration does not arise, and also the actual rate of bottom wear, particularly as regards boring of individual tuyeres, is very much lower. Even in those shops which use an oxygen/steam blast, it is the normal practice to blow with air on a new bottom and also to use air in the latter part of the cast when the highest rate of wear is likely to be encountered, although obviously this latter practice can only be adopted at the expense of some increase in the N content of the finished steel. It is true that the danger of excessive wear can be minimized by variation in the oxygen/steam ratio, but even so individual boring, i.e. enlargement of individual tuyere diameters, does occur. It is essential that tuyeres which bore should be completely




**6** *Section through converter bottom showing entry of copper tubes*

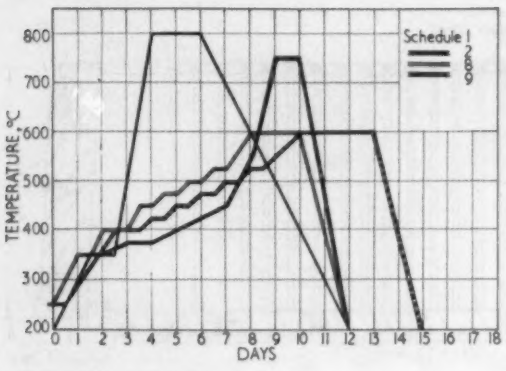
sealed off by blocking in the quickest possible time. The normal method of doing this job, by ramming a fine tar/dolomite mixture into the tuyeres, was found to be much too slow, and the method now employed is to use a metal plug tapped in with a hammer to act as a seal. It is thus possible to seal a dozen tuyeres in a few minutes so that the actual time taken including removal and replacement of the blast box cover is only about 30 min.

It was also thought that the use of magnesite might be of some advantage in minimizing the actual rate of wear. Considerable experimentation was carried out using crushed brick magnesite, grain magnesite, and ramming magnesite in various proportions in the bottom mix. The appearance of some of these bottoms in the converter during operation was quite good, since the use of magnesite largely eliminated the funnelling effect at the tuyeres which is always present and which frequently leads to boring. The rate of wear was, however, in most cases very fast indeed owing to the heavy spalling which took place. In addition the high expansion of the magnesite caused considerable damage to the bottom plates which cracked almost as frequently as when hydrated dolomite was giving a similar effect. Also on a number of bottoms, the rate of boring was considerably accentuated. This was found to be a subsidiary effect of the magnesite expansion. On some bottoms, even when the plate was not cracked, the copper tubes had become distorted thus preventing the free passage of the blast. In such cases the rate of boring was very fast whilst displacement of the copper tubes made effective blocking difficult if not impossible. Altogether the effect, therefore, was far worse than in the linings, and it was decided to abandon further experiments with the use of magnesite.

The methods of sealing the copper tubes into the plate and also making the necessary seal between the bottom plate and blast box ring are two points which are absolutely essential to operation of this process, and failure to accomplish these jobs correctly will bring the bottom to a rapid and untimely end.

The standard practice at present in use for the making of bottoms is as follows. The plate is cleaned and copper tubes 14 mm outside dia., 12 mm inside dia. are passed through the plate which has been drilled to 14·1 mm. These tubes project into the countersunk portion on the underneath side. They have first been coated with a refractory air-setting cement to ensure that they do not move during filling of the mould or subsequent vibration (Fig.6). Pan head rivets are placed in the top of the tubes to prevent any of the bottom mixture entering. The plate is then placed on the vibrating table, the mould set in position, and a grid rested on top of the mould. The grid enables the operators to stand over the mould to distribute the bottom material, and also to ensure that the material does not move or damage the tubes while the moulds are being filled. The tar/dolomite mixture is prepared to a standard procedure: 1000 kg of material 8–15 mm grading is run into the pan mill and is milled dry for 5 min, 6–8% of tar is added, and the whole milled for 20 min; 225 kg of 2–4 mm material is added, milled for a further 5 min; then a further 5% of tar is added followed by 125 kg of 0–2 mm and 100 kg of 0–0·5 mm dolomite, and the whole mixed for a further 10 min, giving a total time in the pan mill of 40–45 min. This mixture is fed from the mill at a temperature of about 70°C into a skip which is lifted by the crane and tipped into the bottom mould. During filling this mould is kept hot by means of a gas ring; a gas burner is also placed underneath the bottom plate. The material, which is very fluid, readily finds its own level. When the mould is full the whole assembly is clamped to the bottom vibrating table and vibrated for 30 min. During this time bubbles of air are constantly breaking through and surplus tar comes to the surface, usually to a depth of a couple of inches, while the top level of the bottom sinks by about 3–4in. If a bottom heating oven is available the new bottom is placed inside and is held at a temperature of 200°C until the oven is fully charged. The bottoms after manufacture are heated in one of three batch bottom-heating ovens in order to coke the tar. It was thought at first that a temperature of 800°C would be necessary to accomplish this and a heating cycle of 12 d was adopted rising to 800°C after 4 d, the bottoms being held at this temperature for 2 d before cooling. Temperatures in this range caused considerable difficulties owing to the growth of the bottom plates and, in view of the fact that most continental plants use a lower temperature, this figure was gradually reduced to a maximum of 600°C (Fig.7).

A considerable number of different schedules were tried out. It soon became obvious that rapid heating-up had a marked effect on the condition of the bottom




**7** *Heating schedules for converter bottoms*

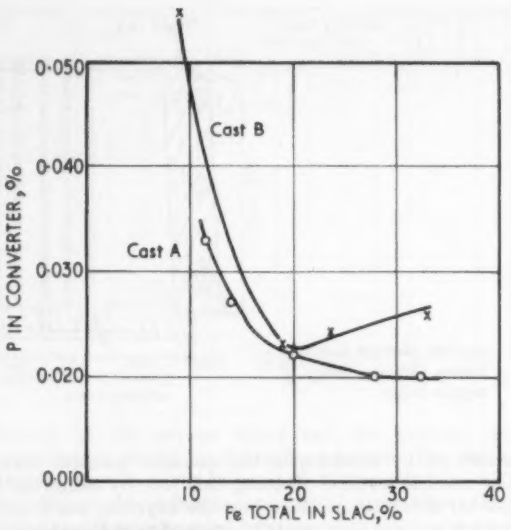
in service. A gradual improvement in bottom life and the installation of a third oven enabled the heating cycle to be increased to 15 d. This has been done primarily by lengthening the period over which the temperature is raised to allow the low volatiles in the tar to evaporate slowly.

It now takes 10 d to reach the maximum temperature of 600°C at which the bottom is held for 3 d and then cooled off for another 2 d. Experiments have, however, shown that this cycle time, and possibly also the maximum temperature, could be reduced without any deleterious effect on the bottom life, but the heating time should not be less than 8 d. When the bottom has been removed from the oven it remains in the dolomite house until shortly before it is required in a converter. The mould is then stripped off and the bottom placed on a stand which enables the operatives to make the seals necessary to prevent the blast penetrating around the periphery of the copper tubes and entering the dolomite. These seals are made by hammering lead wool or lead washers into the countersunk portion of the bottom plate through which the copper tubes project. This is a most important operation and the life of the bottom is largely governed by the efficiency of this seal.

#### Bottom changing

When it is necessary to change a bottom the old one is first removed from the converter and lowered onto a hydraulic jack car located on the slag tracks running below each converter. The jack car is moved underneath a bottom handling crane which lifts the bottom and takes it to the dolomite house. Around the periphery of the new bottom plate, outside the actual dolomite mass, a mixture of clay and waterglass has been laid to make a bed in which a 1-in asbestos rope is placed. This forms a seal between the bottom plate and the sealing ring inside the converter. The bottom is then placed on the jack car and lifted into position in the converter. It is essential that the bottom is located correctly and a pressure of 1000 lb/in² is inserted on the jack car ram to ensure that the bottom is placed right home and that a 100% safe seal is made. Any error here will result in the blast penetrating the joint causing hydration of the bottom and failure after a few blows.

When the new bottom has been positioned the space between it and the lining is filled with a fluid mixture




Cast A—high basicity slag
Cast B—low basicity slag
%P in finished steel:
Cast A—0·023%
Cast B—0·029%
Temp. 1600–1610°C

**8** *Graph showing relationship between %P (converter steels) and %Fe (total) in slag*

of tar and dolomite which has been prepared in the kneader in the dolomite house. This mixture is composed of fine dolomite (0–0·5 mm) prepared in the ball mill together with about 20% of dolomite (0–2 mm) and mixed with 18% of tar; this material is mixed at a temperature of 100°C and is discharged from the kneader into skips which are heated and retained at a temperature of 300°C by means of immersion heaters inserted in a glycerine bath. When the converter is ready for the joint to be poured the skip is elevated to the top of the main building and positioned in a man-operated trolley which can be driven onto the lime monorail system. The skip is moved above the chute leading into the nose of the converter, and the mixture poured. The converter is rocked to ensure that the jointing space is completely filled, after which an oil-gun is lit and the joint burnt in for a period of 6–8 h. The converter is then turned down for inspection of the joint, the copper tubes in the bottom are rodded to remove the pan head rivets and ensure there is no other obstruction, and a final check is made on the lead wool seals. The blast box cover is then positioned and secured and the converter is ready for blowing.

### STEELMAKING PRACTICE

As already stated, we have no air supply suitable for blowing a charge so that all casts at the VLN steelplant are made using an oxygen/steam blast throughout, the purity of the oxygen being 99·5%.

The average compositions of the hot metal used and the steel produced are as follows:

| | |
|---|---|
| *Hot metal* | Average composition, %: C 3·8, Si 0·35, S 0·024, P 1·8, Mn 0·8, $N_2$ 0·0050, |
| *Steel* | Average composition, %: C 0·05, S 0·022, P 0·022, Mn 0·30, $N_2$ 0·0011, Cu 0·03, Ni 0·05, Sn 0·01 |

The refining of the charge is carried out in two distinct blowing periods. It is aimed to bring the converter down after the first blow with the slag composition in the range of 10–14%Fe and 18–21%$P_2O_5$; this corresponds to a metal composition of 0·025%C and 0·04–0·07%P. After 70% of the slag has been poured off, extra lime is fed and the charge is blown for a second time to obtain a metal composition of about 0·02%C and 0·02%P with a slag containing 24%Fe and 11%$P_2O_5$. The average charge to tap time is 30 min (varying from 22 to 40 min), and using one converter it has been found possible to blow 17 charges in an 8-h shift.

Before describing the practice in greater detail, it is useful to comment on three factors which have determined the development of the process.

1. *The specified phosphorus contents of the steel*

As VLN steel is used for the most difficult extra deep-drawing applications, it is necessary that the P content should be lower than that generally required in ordinary basic Bessemer steel. Kosmider and Schenk[2] have shown that P contents in the finished steel of the order of 0·025% are at the lowest level to be expected from the refining of high-P irons in bottom-blown converters. It is, therefore, necessary as normal practice to aim for the lowest P content in the finished steel. There appears to be a limit to the total Fe content of the tapping slag beyond which no benefit is obtained in dephosphorization. As illustrated (Fig.8) it is possible by extended blowing to cause a reversion of the dephosphorizing reaction so that the P content increases as the blow progresses. With slags at the high level of basicity necessary to obtain low-P steels, the total Fe content at which this reversion effect occurs is of the order of 30%, this figure increasing with increase in the basicity of the slag.

Figure 8 represents the progress of dephosphorization of two casts in which no additional lime was fed between blows. The weights of lime charge and final slag compositions of the two casts were as follows:

*Cast A* (Lime 11 tons); Final slag composition, %: $SiO_2$ 2·1, FeO 30·3, $Fe_2O_3$ 12·2, $Al_2O_3$ 4·1, MnO 2·0, CaO 37·5, MgO 3·8, $P_2O_5$ 8·3, Total Fe 32·4

*Cast B* (Lime 9¼ tons); Final slag composition, %: $SiO_2$ 3·2, FeO 29·3, $Fe_2O_3$ 14·4, $Al_2O_3$ 2·0, MnO 3·2, CaO 35·1, MgO 2·5, $P_2O_5$ 10·7, Total Fe 33·0

The degree of control required in the timing of the second blow with a normal two-blow practice is indicated by the fact that the sampling points for the two casts correspond to blowing periods of 15 s.

This phenomenon of overblowing has been explained by the work of Oelsen and Maetz.[3] In the iron oxide-rich region of the $CaO–P_2O_5–FeO$ system, the solution of the oxides separates into two immiscible layers, one tending to the composition $3CaO.P_2O_5$ and the other rich in FeO. The FeO content at which this effect occurs increases as the $CaO/P_2O_5$ ratio (mol) increases above 3·0. The overall slag compositions obtained in the refining of high-phosphorus iron correspond to basicities greater than that of the tri-calcium phosphate so that entering this region of immiscibility tends to reduce the stability of the $P_2O_5$ constituent in the slag and reversion of the dephosphorizing reaction occurs.

It is generally found that if a charge is overblown, so that the P content is tending to increase, there is a further marked increase in the P content in the steel ladle. This is because MnO acts similarly to FeO in promoting this immiscibility effect, so that deoxidizing with ferro-manganese in the steel ladle can cause P reversion greater in extent that is attributable to the deoxidizing effect alone.

2. *Lime quality*

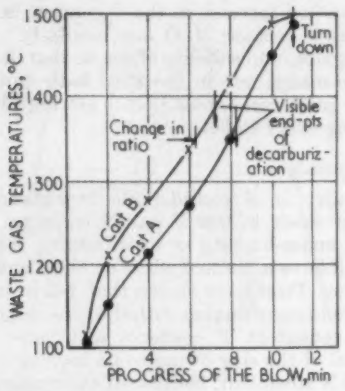
Lime quality is of considerable importance in the making of steels of low P and S contents. Its size, degree of under-burning or over-burning, $SiO_2$ and S content all have a marked effect on the reactions during blowing. Tests have shown that 1–2-in lump lime does promote early fluxing with the consequent benefit of more consistent P contents and more effective pouring off of the slag owing to its increased fluidity. At the VLN steelplant, because of calcination in shaft kilns, our lime size ranges from 2–6 in.

Since dephosphorization is a slag–metal reaction, occurring towards the end of the first blow, the temperature of the slag tends to be higher than that of the metal. This is not a desirable effect as dephosphorization of the iron is favoured by low temperatures. If the lime is overburnt, making it hard, dense and difficult to flux, dephosphorization is delayed and this causes the temperature difference between slag and metal to be accentuated. If the lime is underburnt, then the calcination occurring during blowing reduces the slag temperature. On occasions when overburnt lime has been used in the initial charge it has been found necessary to feed limestone instead of lime between blows to obtain the required low P content. Generally the lime at the VLN plant is not completely calcined, the ignition loss ($CO_2$) being of the order of 4%. With regard to the S content of the lime, it is possible to restrict this to 0·02% by limiting to 12:1 the ratio of blast-furnace to coke-oven gas used to calcine the limestone.

The $SiO_2$ content of the lime varies in the range of 1·0–5·0%. This represents a much greater variation in the effective 'CaO' content of the lime as account has to be taken of the 'CaO' required to combine with the $SiO_2$ content. Because of this effect, and also the variable lime losses due to ejections, the normal practice to obtain a consistent final slag basicity is to make a standard addition of at least 1 ton of lime fines between the first and second blows.

3. *Oxygen/steam ratio*

In the initial stages of development the ratio was restricted to levels not higher than 0·9:1 oxygen/steam by volume (47% oxygen). It was thought that ratios higher than this would cause a decrease in bottom life. This restriction caused our scrap usings to be limited to a maximum of 5%. Further experiments have shown that ratios up to 1·5:1 (60% oxygen) can be used with no marked decrease in bottom life provided that it is lowered to 0·7:1 (40% oxygen), during dephosphorization. This change in practice has had the effect of increasing our scrap usings. With a hot metal composition of 2·0%P, 0·4%Si, and a hot metal temperature of 1200°C scrap consumption with an 0·9:1 oxygen/steam ratio would be about 5% of the total charge, whereas blowing at 1·5:1 ratio decreasing to 0·7:1 increases this to 10%. If the high-P hot metal is used, a scrap consumption of the order of 15% of the total charge can be obtained.




Cast A—0·9 $O_2/H_2O$ throughout
Cast B—1·5→0·5 $O_2/H_2O$

**9** *Results of suction pyrometer tests on converter waste gases*

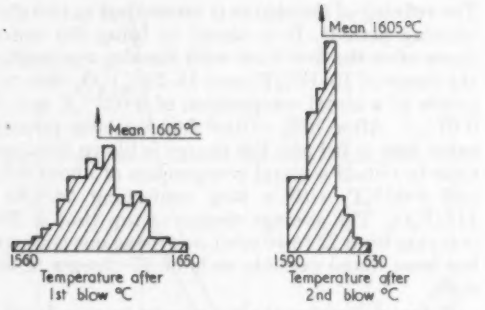
Decreasing the oxygen/steam ratio during the blow has a significant effect on the development of heat within the charge. Whereas normally when blowing throughout with a blast of fixed composition, the temperature of the charge increases steadily up to the end of the blow, a changing ratio practice results in an earlier development of the finishing temperature (Fig.9). This promotes earlier fluxing of the lime, and slags containing 10–12%Fe are found to be completely fluxed and fluid enough to allow approximately 70% to be poured off before beginning the second blow. This may well be the reason why it is possible to melt scrap up to 15% of the total charge weight in the relatively short blowing time of 9–10 min.

#### General operational procedure

All the lime, scrap, and hot metal are charged in this order into the converter. The weight of lime is varied in accordance with the weight and the P and Si contents of the hot metal, aiming for a 70% excess 'CaO' over the compounds $2CaO.SiO_2$ and $3CaO.P_2O_5$. The effective 'CaO' content of the lime (defined as $\%CaO - 3 \times \%SiO_2$) averages 85%. The scrap used is in the form of plate or slab crops up to 6in thick.

The nominal capacity of the converter is 50 tons, but because of the reduced tendency for ejections, owing to the smaller volume of the oxygen/steam blast as against air, we normally find it is possible to tap 63 tons of steel with total metal charge weight of 74 tons. There are indications, provided the Si content of the hot metal is less than 0·4%, that 70 tons of steel could be tapped without experiencing excessive ejections during blowing. In contrast to normal bottom-blown converter practice, it is not necessary to stop blowing to clean the nose of the converter. As previously mentioned, the first blow is carried out using an oxygen/steam ratio of 1·5:1 dropping to 0·7:1 during dephosphorization. The blast box pressure is 35–40 lb/in² and with the blow section of 300 cm² the time of the first blow, charging 74 tons of hot metal, is 10 min. This can decrease to 9 min as the percentage of scrap consumed is increased.

The laboratory with the aid of an ARL Quanto-Vac provides a rapid analysis service so that the composition of the bath metal can be obtained within 2 min of




**10** *Range of bath temperatures after 1st and 2nd blows (189 casts)*

dispatching the sample. Taking into account the Mn content of the hot metal, the relationship between the Mn and P contents of the bath metal is used as an indication of the basicity of the slag. After about 70% of the first slag has been taken off, 20 cwt of lime fines are fed into the converter and the charge blown for a further 30–60 s. The oxygen/steam ratio used in the second blow can vary between 0·5:1 and 1·5:1 depending on the time of the blow and temperature of the bath. Blowing for 60 s at 0·5 ratio instead of 1·5 can make a difference of up to 40°C in the final temperature. As illustrated in Fig.10 adjustment of the oxygen/steam ratio for the second blow allows the final steel temperature to be controlled within a narrow range. The optimum tapping temperature consistent with keeping ladle skulls to the minimum and producing low P contents has been found to be in the range of 1595–1615°C.

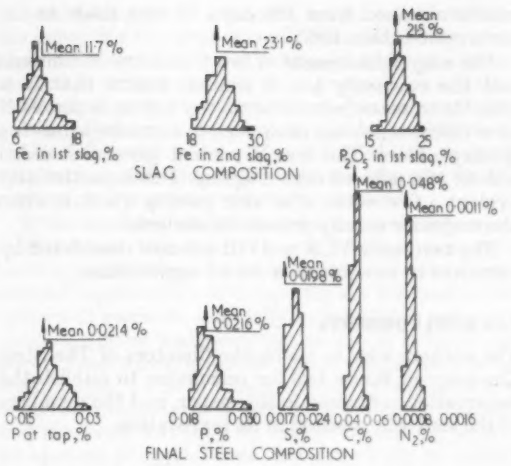
Before the charge is tapped a dam of crushed slag is made in the mouth of the converter. During tapping, the required quantity of crushed cold ferro-manganese is added directly to the steel ladle aiming for a Mn content of 0·3%. The Mn consumption (75%Mn, 6%C) is of the order of 15 lb/ton of steel. The yield of ingot steel from total metal charged averages 84·5% and the overall yield including butts and skulls is 86·0%. The ingot mould sizes used range from 10–20 tons, so that careful control has to be exercised over the charge weights and teeming levels in the mould to avoid heavy butt-ends.

The control of the slag composition and the range of P, S, C, and N contents of the steel produced in the VLN steel plant are indicated in a series of histograms (Fig.11) covering one week's production, 189 casts. The hot metal composition for this period was as follows:

| | Si | S | P | Mn |
|---|---|---|---|---|
| Mean value | 0·373% | 0·021% | 1·94% | 0·47% |
| Range | (0·30–0·52) | (0·014–0·027) | (1·89–2·10) | (0·40–0·59) |

**TABLE II C and O contents of bomb samples taken from converter**

| Cast | Period | %C | %O |
|---|---|---|---|
| 1 | After 1st blow | 0·013 | 0·088 |
| 1 | After 2nd blow | 0·010 | 0·098 |
| 2 | After 1st blow | 0·022 | 0·060 |
| 2 | After 2nd blow | 0·018 | 0·094 |
| 3 | After 1st blow | 0·018 | 0·076 |
| 3 | After 2nd blow | 0·015 | 0·080 |




**11** *Production data relating to 189 consecutive casts*

*Phosphorus content*

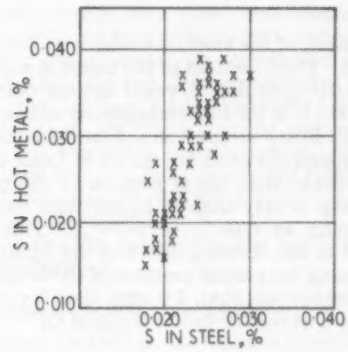
The mean P content at tap is of the same value as the final P content of the steel, 0·021%. This does not represent the normal relationship between the P content at tap and in the steel ladle. On individual casts it is frequently found that there is either a distinct drop or increase in the P content.

The basicity of the tapping slag, using as an index the V ratio

$$\frac{CaO}{SiO_2 + 0{\cdot}634\ P_2O_5}$$

is of the order of 3·5–4·0. At this level it is found that variation in the total Fe content of the slag in the range of 20–28% has no readily observed effect on either the tap or ladle P contents. The extent to which the P content of the steel ladle sample differs from that of the converter seems to be determined by the degree of interaction of three factors:

(i) the P content of the converter sample at tap can vary between 0·015% and 0·03% for the same slag composition. The higher level is generally associated with either high metal or high slag temperatures




**12** *Relationship between S content in hot metal and S content in finished steel*

(ii) the cooling effect of making the dam and pouring the charge into the steel ladle tends to cause a decrease in the P content

(iii) the ferro-manganese addition to the steel ladle reduces the state of oxidation of both the metal and slag tending to cause an increase in P content of the steel.

Charges in which little or no ferro-manganese is added to the ladle always show a decrease in P content from converter to ladle sample of the order of 0·010%. With the normal addition of ferro-manganese, it is generally found that when tapping with a low P content there is an increase in P in the ladle while with a high-tapping P there is a decrease.

There is a special case of over-blown charges with excess total Fe contents in the tapping slag. These charges always show an increase in P content in the steel ladle sample.

*Sulphur content*

The mean S content in the steel for the week under consideration was 0·020%. Taking into account the concentration effect of oxidizing the metalloids out of the iron, this represents an average desulphurization of 15%. The degree of desulphurization increases with the S content of the hot metal (Fig.12). With 0·04%S in the hot metal the desulphurization is of the order of 40%.

**TABLE III Comparison of VLN B20 grade and OH 020 grade**

**Pit analysis**

| | %C | %S | %P | %Mn | %Ni | %Cu | %Sn | $\%N_2$ |
|---|---|---|---|---|---|---|---|---|
| VLN B20 | 0·048 | 0·019 | 0·021 | 0·29 | 0·04 | 0·03 | 0·01 | 0·00106 |
| OH 020 | 0·067 | 0·025 | 0·013 | 0·33 | 0·05 | 0·07 | 0·01 | 0·004 |

**Mechanical properties of cold reduced and annealed material**

| | Mean Rockwell, scale B | Mean Olsen | Yield point, tons/in² | Ultimate tensile strength, tons/in² | % elongation, 8in | % elongation, 2in |
|---|---|---|---|---|---|---|
| VLN B20 | 45·8 | 410·6 | 11·96 | 20·13 | 35·13 | 50·0 |
| OH 020 grade | 44·8 | 411·5 | 11·81 | 20·08 | 35·23 | 50·1 |

**Hardness of hot rolled band (Rockwell)**

VLN steel: 59·0 OH: 62·5

*Carbon content*

The C content of the steel is consistently low, averaging 0·048%. The C content of the metal at tap is of the order of 0·015% so that it would appear that most, if not all, of the C in the ferro-manganese addition is held in the steel. Bomb samples have been taken and the C and O contents obtained are shown in Table II. These results indicate that the O content of the converter metal at tap is only slightly higher than that of OH steel tapping at 0·05% to 0·06%C. This can be attributed to the diluting effect of the hydrogen and steam causing the partial pressure of CO in the bath to be considerably less than 1·0 atm, thus favouring the removal of C at relatively low levels of O.

*Nitrogen content*

The N content of the steel is consistently very low, averaging 0·0010% with 15% down to 0·0008%. Since the initial N content of the hot metal is 0·005–0·006% it would seem that the purging effect of the oxygen/steam blast causes a reduction in the N content of 80%.

## PROPERTIES OF VLN STEEL

Table III compares the average pit analyses and mechanical properties of VLN and OH steels making the same grade. The values shown are the averages of results obtained from 100 casts of steel made in the same period, Dec. 1960.

The easy achievement of low C and low N contents and the relatively low S content means that it is possible to manufacture bottle top ingots in the VLN steel plant, which can be applied to extra deep drawing quality orders. The low N content gives the added benefit of a reduced rate of ageing. This is particularly evident a few weeks after skin passing which is when the customer usually presses the material.

The two steels VLN and OH are now considered by ourselves to be equivalent for all applications.

## ACKNOWLEDGMENTS

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## REFERENCES

1. G. G. Fletcher and R. A. Pullen: *J. Inst. Fuel*, 1961, **34**, 47–52.
2. H. Kosmider and H. H. Schenk: *Stahl Eisen*, 1957, **77**, 917–926.
3. W. Oelsen and H. Maetz: *Arch. Eisenhütt.*, 1948, **19**, 111–117.

# Survey of the technical and scientific uses of computers in the iron and steel industry

*D. G. Owen and R. J. Taylor*

## INTRODUCTION

OUR UNDERSTANDING of iron- and steelmaking processes, the extent of our control over them, and our ability to design new and improved processes, depend increasingly on the research that goes on in all parts of the industry. An important aspect of any research project is calculation, whether it be to estimate from a theoretical basis or to assess statistically the results of an experiment; often these calculations are only practicable with the aid of machines.

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Mr Owen is assistant head of the Operational Research and Cybernetics Department of The United Steel Companies Ltd, and Mr Taylor was head of the Computer Applications Section, Operational Research Department of BISRA when this paper was written. Mr Taylor is now with the Operational Research Division of Associated Industrial Consultants Ltd.

## SYNOPSIS

*Seven electronic digital computers have so far been installed in the British iron and steel industry, and three more are known to be on order. A general description of each installation is given and the work done by these machines is surveyed. Not all the computers are used for scientific and technical work, most of which is done on the three Pegasus computers. Examples of scientific and technical calculations are given, and these are discussed under the following headings: (a) conventional scientific research, (b) mathematical statistics, (c) operational research, (d) design and development, (e) control and special commercial applications. The final section of the paper discusses some of the problems in future developments.*

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Against this background, electronic computers can be viewed from two angles. Some regard a computer mainly as a means for speeding up existing research.

Others, taking that for granted, are more interested in the computer for what it could contribute to production efficiency: a computer's capacity and speed might be used to control furnaces more precisely, to schedule production or to coordinate the movements and processing of many varied products. Such possibilities as these, if they are to be made real, need new research and experiment, and involve drastic changes in the way many of our processes are controlled.

While the computer is a tool for the everyday use of scientist and technician, it also inevitably expands their opportunities to turn arts into sciences. 'Commercial' applications of computers are themselves the subject of research, especially in connexion with production control and planning, and so it is no longer easy to see where scientific and technical uses stop. Accordingly, we have begun this survey with a review of all the computers at present installed in the industry and the work that they do, before attempting to give an account of applications that are wholly or mainly 'scientific' or 'technical'.

## DEFINITION

The term 'computer' is commonly borrowed for almost any 'box of tricks' which transforms a few inputs into more useful outputs. It must be made clear that, for the purpose of this paper, the term is used to mean an electronic digital computer with provision for stored, easily varied programs (for a further explanation of these terms *see* ref.1). Because such a machine can be programmed with tremendous flexibility, the term also implies the description 'general-purpose', although evidently there is no suggestion that all these computers are equally suited to all purposes. A 'general-purpose' computer may easily be part of a 'special-purpose' system.

Analogue simulators (the term 'computer' is to be avoided here) form such a different category of machine that they must be considered separately. This is not to say that analogue and digital cannot meet: in many control systems both methods will be used. The present review is restricted to digital computers.

## COMPUTER INSTALLATIONS

By January 1961, seven electronic digital computers had been installed in the British iron and steel industry, and three other definite orders had been placed with computer manufacturers; some other steel companies were seriously considering the potentialities of computers, and further orders are likely during 1961. The ten machines already installed or ordered are listed in Table I, and further technical details of the first seven installations are given in Table II.

Several firms which have close connexions with iron and steel also have computers: among these are Ford Motor Co. Ltd,[2] Guest Keen and Nettlefolds (Midlands) Ltd,[3] and Newton Chambers and Co. Ltd.[4]

No attempt has been made to compile a list of steel companies which use the computer service bureaux provided by computer manufacturers, universities and technical colleges, but the work of member firms of BISRA who use the BISRA Pegasus on a service basis is described below.

In the following paragraphs the ten installations are briefly described.

### Tube Investments Ltd IBM 650 computer

Installed in July 1957 in the Group's technical centre at Walsall, this machine has been applied to commercial work for several manufacturing units. It is occasionally used for scientific calculations.

Commercial applications include calculations of standard costs, etc., but the most interesting computer routine schedules the final processes in the manufacture of tubes. Delivery dates are determined for orders, production routes are selected, and machine-loadings are forecast. This type of work needs several separate processing runs on the present computer, which in consequence is to be replaced by a more powerful installation.

Only a small amount of time is spent on research calculations, which are mainly concerned with electrical engineering problems, welding, etc.

### BISRA Pegasus 1 computer

Experience in the use of the Ferranti Mark I computer at Manchester University indicated that BISRA could justifiably install their own machine. In November 1957 the present computer was installed in the Operational Research Department, Park Lane, London; in January 1959 the department and computer were transferred to the Battersea Laboratories of BISRA. Initially the computer was intended to be used by BISRA and member firms for research and as a pilot plant for commercial applications.

The most frequent applications arising in BISRA have been concerned with statistical analyses and operational research calculations. Nevertheless all the research divisions in BISRA have used the machine for various numerical calculations, particularly for the analysis of automatically recorded data. Naturally, many of the scientific staff in these divisions have learnt to program and operate the computer, although they usually work in conjunction with specialist programmers.

During 1960 15 member firms ran their own programs on the BISRA computer; this figure does not include

**TABLE I Computers installed or ordered**

| Company | Date installed | Type | Remarks |
|---|---|---|---|
| Tube Investments Ltd | July 1957 | IBM 650 | |
| BISRA | November 1957 | Ferranti Pegasus 1 | |
| The United Steel Companies Ltd | February 1958 | Ferranti Pegasus 1 | Large drum and magnetic tape to be added in 1961 |
| Stewarts and Lloyds Ltd | April 1958 | Leo II | Drum to be added in 1961 |
| The United Steel Companies Ltd | March 1960 | ICT 1202 | |
| The Steel Company of Wales Ltd | March 1960 | Ferranti Pegasus 1 | With large drum |
| Samuel Fox & Co. Ltd | February 1961 | Elliott 803 | With special input/output equipment and measuring devices |
| The Steel Company of Wales Ltd | (1961) | IBM 650 | |
| Dorman Long (Steel) Ltd | (1962) | IBM 1401 | With a magnetic disc file |
| Tube Investments Ltd | (1962) | IBM 7070 and 1401 | With magnetic tape; will replace IBM 650 (above) |

**TABLE II Details of computer installations in the steel industry (1 January 1961)**

| User | TI (Group Services) Ltd | BISRA | United Steel Cos Ltd | Stewarts & Lloyds Ltd | United Steel Cos Ltd | Steel Company of Wales Ltd | Samuel Fox & Co. Ltd |
|---|---|---|---|---|---|---|---|
| Manufacturer | IBM (United Kingdom) Ltd | Ferranti Ltd | Ferranti Ltd | Leo Computers Ltd | ICT Ltd | Ferranti Ltd | Elliott Brothers (London) Ltd |
| Computer | IBM 650 | Pegasus 1 | Pegasus 1 | Leo II | ICT 1202 | Pegasus 1 (large drum) | 803 |
| Date | Hired (July 1957) | Purchased (Nov. 1957) | Purchased (Feb. 1958) | Purchased (April 1958) | Hired (Feb. 1960) | Purchased (March 1960) | Purchased (Feb. 1961) |
| Peripheral equipment | Up to 3 independent input channels, sterling conversion unit; 2 accounting machines | Input: 2 paper tape readers. Output: 3 paper tape punches | Input: 2 paper tape readers. Output: 3 paper tape punches, 1 teleprinter (4 magnetic tape decks being added) | Up to 3 independent input and 3 independent output channels. Input: 3 card readers and 2 tape readers. Output: 3 card punches and 2 tabulators | Punched card input and output | Input: 2 paper tape readers. Output: 3 paper tape punches | Equipment for receiving manual and automatic signals and for displaying information and instructions to mill staff; also paper tape reader and punch |
| Off-line equipment | Punched card equipment | Printing and tape-preparation: 3 teleprinters | Printing and tape-preparation: 5 teleprinters, 2 keyboard punches | Punched card equipment | Punched card equipment | Printing and tape-preparation: 3 teleprinters | |
| Accommodation | A room, 80 ft × 20 ft, in converted premises, with air conditioning | Purpose-built room, 22 ft × 19 ft, on the top floor of a 3-storey office block. Extractor fans are fitted above the computer with enclosing metal ducting | Ground floor room, 22 ft × 18 ft, forced ventilation. (Air conditioning being installed for enlarged room) | Purpose-built room, 80 ft × 30 ft on the first floor of a new office block, with air cleaning | Occupies part of a very large ground floor room. Forced ventilation | A room, 29 ft × 25 ft, in a Terrapin timber building set on a concrete base, with air conditioning, in Port Talbot works near the slab yard of the continuous strip mill | Purpose-built 250 ft² room adjoining billet mill (computer only: other equipment installed at mill) |
| Maintenance staff | Manufacturer's engineer (shared), single shift | 2 engineers, single shift, with hours slightly staggered | 4 engineers, single shift. One 'on call' each evening | 4 engineers shared with other departments, single shift | Manufacturer's engineer (shared); one day/week given over to maintenance | 1 engineer, single shift | 4 engineers, shared with other departments. 3 shifts/day |
| Operating staff | 1 (two other trained operators are available) | 1 (also programmers) | 1 (also programmers) | 2 (operation by programming staff is restricted) | 1 | 1 (also programmers) | Mill staff |
| Programming staff | 11 | About 10 in various departments | About 20 in various establishments | 7 | 3 | 5 | None (program written by manufacturer's staff) |
| *Computer utilization 1960* | | | | | | | |
| *Averages per week, h* | | | | | | | |
| Total time switched on | 41½ | 55½ | 99 | 53 | | 42 | |
| Scheduled maintenance (including staff training and modifications to equipment), | 2½ | 8½ | 6 | 6½ | | 5 | |
| Lost time (including all faults), | 2 | 1½ | 2 | 2½ | Analysis not available | 1 | System to work 140 h/week when program testing and operator training is complete |
| Program testing (including development) | 10 | 10½ | 27+7* | 8 | | 13 | |
| Miscellaneous, e.g. demonstrations (including idle time) | 2 | 10 | 3 | 0 | | 9½ | |
| Production running (established programs) | 24½ | 25 | 29+26* | 36 | | 13½ | |

* Time used by Sheffield University.

firms which merely contract with BISRA to run certain standard calculations. Of the steel firms, the operational research departments of The Steel Company of Wales (before the purchase of their own Pegasus), Richard Thomas and Baldwins, and Guest Keen and Nettlefolds (Steel) have been the major users. One of the few commercial applications is the work of the British Coking Industry Association who run routine quarterly analyses of coke returns with some statistical checks; the programs were prepared by BISRA.

About 5% of the computer running time is used for demonstration purposes and for training during BISRA programming courses. In 1960 three computer courses were held, attended by 40 representatives of the steel industry, all of whom prepared at least one working program before the end of each course.

#### The United Steel Companies Ltd Pegasus 1 computer

The computer was installed in February 1958 in the company's central department of operational research and cybernetics in Sheffield, and is used jointly with the University of Sheffield. It was purchased primarily for research, but also with the intention of applying it, at least on a pilot scale, to production jobs for the branches of the company. One such application is now a regular service for designing steel structures;[5] computer data and results are transmitted by teleprinter link between Scunthorpe and Sheffield.

In addition to a central programming team, there are groups of programmers in several of the branches and in the company's central research and development department.

During 1960 the computer was used for an average of about 100 h/week, of which about one-third was accounted for by the University. The installation is at present being enlarged; magnetic tape units and some other equipment are being added.

#### Stewarts and Lloyds Ltd Leo II computer

Study of computer applications began in 1955, and a section of the Corby payroll was handled weekly by the Leo computing service in London from May 1957. In April 1958 a Leo II computer was installed at Corby to take over and extend that work.

The computer is now working a five-day week, one shift per day with late night working twice a week. Routines in regular use include payroll and warehouse invoicing and stock control. A program has been developed to carry out daily calculations in connexion with blending the ores produced from a number of mines.[6] Technical applications of the computer include computation of various properties of tubes and the stressing of pipework.

The computer's storage capacity is to be increased by attaching a magnetic drum.

#### The United Steel Companies Ltd ICT 1202 computer

This machine was installed in March 1960 in the company's head office. Earlier some programs had been tested at one of the manufacturer's installations.

The main purpose for this machine is to build up experience of applying a computer to accounting and related work, and this has commenced with programming a stores stock control and accounting system for one of the smaller branches of the company. Payroll and cost accounting for that branch is now also handled by the computer, and the control of stocks of parts and assemblies in the manufacture of diesel locomotives is being programmed.

#### The Steel Company of Wales Ltd Pegasus 1 computer

After the company had made extensive use of the BISRA computer, a similar machine was installed in March 1960 at Port Talbot in the Operational Research Department. The computer is used for research and development work, but experience is also being gained with it on commercial work.[7] However, this commercial experience will probably be restricted to those operational research investigations which bear indirectly on routine application. The utilization of the machine is increasing with the recruitment of suitable staff and as new applications are developed in connexion with operational research investigations and for statistical analyses of works data.

#### Samuel Fox and Co. Ltd Elliott 803 computer

This installation is an 'on-line' system, consisting of a digital computer, automatic billet-length measuring equipment, and a number of units for displaying instructions to (and receiving information from) the operating staff of the billet mill and cut-up line. The computer calculates the optimum lengths to cut from each billet as it comes from the mill, so as to maximize yield, and communicates with mill staff over a wide area.[8]

The computer may also be used for technical or scientific calculations at weekends, and is capable of being enlarged to handle other production work on a time-sharing basis.

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(i) conventional scientific research
(ii) mathematical statistics
(iii) operational research
(iv) design and development
(v) control and special commercial applications.



• Time used by Sheffield University.

**TABLE II Details of computer installations in the steel industry (1 January 1961)**

| User | TI (Group Services) Ltd | BISRA | United Steel Cos Ltd | Stewarts & Lloyds Ltd | United Steel Cos Ltd | Steel Company of Wales Ltd | Samuel Fox & Co. Ltd |
|---|---|---|---|---|---|---|---|
| Manufacturer | IBM (United Kingdom) Ltd | Ferranti Ltd | Ferranti Ltd | Leo Computers Ltd | ICT Ltd | Ferranti Ltd | Elliott Brothers (London) Ltd |
| Computer | IBM 650 | Pegasus 1 | Pegasus 1 | Leo II | ICT 1202 | Pegasus 1 (large drum) | 803 |
| Date | Hired (July 1957) | Purchased (Nov. 1957) | Purchased (Feb. 1958) | Purchased (April 1958) | Hired (Feb. 1960) | Purchased (March 1960) | Purchased (Feb. 1961) |
| Peripheral equipment | Up to 3 independent input channels, sterling conversion unit; 2 accounting machines | Input: 2 paper tape readers. Output: 3 paper tape punches | Input: 2 paper tape readers. Output: 3 paper tape punches, 1 teleprinter (4 magnetic tape decks being added) | Up to 3 independent input and 3 independent output channels. Input: 3 card readers and 2 tape readers. Output: 3 card punches and 2 tabulators | Punched card input and output | Input: 2 paper tape readers. Output: 3 paper tape punches | Equipment for receiving manual and automatic signals and for displaying information and instructions to mill staff; also paper tape reader and punch |
| Off-line equipment | Punched card equipment | Printing and tape-preparation: 3 teleprinters | Printing and tape-preparation: 5 teleprinters, 2 keyboard punches | Punched card equipment | Punched card equipment | Printing and tape-preparation: 3 teleprinters | |
| Accommodation | A room, 80 ft × 20 ft, in converted premises, with air conditioning | Purpose-built room, 22 ft × 19 ft, on the top floor of a 3-storey office block. Extractor fans are fitted above the computer with enclosing metal ducting | Ground floor room, 22 ft × 18 ft, forced ventilation. (Air conditioning being installed for enlarged room) | Purpose-built room, 80 ft × 30 ft on the first floor of a new office block, with air cleaning | Occupies part of a very large ground floor room. Forced ventilation | A room, 29 ft × 25 ft, in a Terrapin timber building set on a concrete base, with air conditioning, in Port Talbot works near the slab yard of the continuous strip mill | Purpose-built 250 ft² room adjoining billet mill (computer only: other equipment installed at mill) |
| Maintenance staff | Manufacturer's engineer (shared), single shift | 2 engineers, single shift, with hours slightly staggered | 4 engineers, single shift. One 'on call' each evening | 4 engineers shared with other departments, single shift | Manufacturer's engineer (shared); one day/week given over to maintenance | 1 engineer, single shift | 4 engineers, shared with other departments. 3 shifts/day |
| Operating staff | 1 (two other trained operators are available) | 1 (also programmers) | 1 (also programmers) | 2 (operation by programming staff is restricted) | 1 | 1 (also programmers) | Mill staff |
| Programming staff | 11 | About 10 in various departments | About 20 in various establishments | 7 | 3 | 5 | None (program written by manufacturer's staff) |
| *Computer utilization 1960* | | | | | | | |
| *Averages per week, h* | | | | | | | |
| Total time switched on | 41½ | 55½ | 99 | 53 | | 42 | |
| Scheduled maintenance (including staff training and modifications to equipment), | 2½ | 8½ | 6 | 6½ | | 5 | |
| Lost time (including all faults), | 2 | 1½ | 2 | 2½ | | 1 | |
| Program testing (including development) | 10 | 10½ | 27+7* | 8 | Analysis not available | 13 | System to work 140 h/week when program testing and operator training is complete |
| Miscellaneous, e.g. demonstrations (including idle time) | 2 | 10 | 3 | 0 | | 9½ | |
| Production running (established programs) | 24½ | 25 | 29+26* | 36 | | 13½ | |

* Time used by Sheffield University.

firms which merely contract with BISRA to run certain standard calculations. Of the steel firms, the operational research departments of The Steel Company of Wales (before the purchase of their own Pegasus), Richard Thomas and Baldwins, and Guest Keen and Nettlefolds (Steel) have been the major users. One of the few commercial applications is the work of the British Coking Industry Association who run routine quarterly analyses of coke returns with some statistical checks; the programs were prepared by BISRA.

About 5% of the computer running time is used for demonstration purposes and for training during BISRA programming courses. In 1960 three computer courses were held, attended by 40 representatives of the steel industry, all of whom prepared at least one working program before the end of each course.

#### The United Steel Companies Ltd Pegasus 1 computer

The computer was installed in February 1958 in the company's central department of operational research and cybernetics in Sheffield, and is used jointly with the University of Sheffield. It was purchased primarily for research, but also with the intention of applying it, at least on a pilot scale, to production jobs for the branches of the company. One such application is now a regular service for designing steel structures;[5] computer data and results are transmitted by teleprinter link between Scunthorpe and Sheffield.

In addition to a central programming team, there are groups of programmers in several of the branches and in the company's central research and development department.

During 1960 the computer was used for an average of about 100 h/week, of which about one-third was accounted for by the University. The installation is at present being enlarged; magnetic tape units and some other equipment are being added.

#### Stewarts and Lloyds Ltd Leo II computer

Study of computer applications began in 1955, and a section of the Corby payroll was handled weekly by the Leo computing service in London from May 1957. In April 1958 a Leo II computer was installed at Corby to take over and extend that work.

The computer is now working a five-day week, one shift per day with late night working twice a week. Routines in regular use include payroll and warehouse invoicing and stock control. A program has been developed to carry out daily calculations in connexion with blending the ores produced from a number of mines.[6] Technical applications of the computer include computation of various properties of tubes and the stressing of pipework.

The computer's storage capacity is to be increased by attaching a magnetic drum.

#### The United Steel Companies Ltd ICT 1202 computer

This machine was installed in March 1960 in the company's head office. Earlier some programs had been tested at one of the manufacturer's installations.

The main purpose for this machine is to build up experience of applying a computer to accounting and related work, and this has commenced with programming a stores stock control and accounting system for one of the smaller branches of the company. Payroll and cost accounting for that branch is now also handled by the computer, and the control of stocks of parts and assemblies in the manufacture of diesel locomotives is being programmed.

#### The Steel Company of Wales Ltd Pegasus 1 computer

After the company had made extensive use of the BISRA computer, a similar machine was installed in March 1960 at Port Talbot in the Operational Research Department. The computer is used for research and development work, but experience is also being gained with it on commercial work.[7] However, this commercial experience will probably be restricted to those operational research investigations which bear indirectly on routine application. The utilization of the machine is increasing with the recruitment of suitable staff and as new applications are developed in connexion with operational research investigations and for statistical analyses of works data.

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(ii) mathematical statistics
(iii) operational research
(iv) design and development
(v) control and special commercial applications.

The first of these represents what is normally meant by scientific work; the second has, during the last few years, begun to play an increasingly important part in the analysis of experimental results; (iii) is concerned with the application of scientific method to management problems, and particularly to those concerned with control in complex situations. The last two represent the outcome of the application of scientific method to problems of design and control. Each of these classifications will be considered more fully in the following section.

#### Conventional scientific research

The research worker often faces the dilemma of whether to try to calculate the likely outcome of an experiment or to find the answer by performing the experiment. If the experiment would be expensive or lengthy, it is obviously desirable to explore the possibilities first by calculation, and the availability of computers is now enabling investigators to carry out such explorations with theoretical models instead of by 'backing hunches'.

In the design of experimental furnaces, for example, the effects of some features can be predicted by solving equations before the furnace is built. As a result, experimentation can be directed so as to produce useful results from the start.

The properties and behaviour of furnaces of all kinds have always claimed a big part of the industry's research effort, and mathematical formulations of the relationships affecting furnace performance are still sought. The testing of such formulae against observed data is a task which is almost impossible without a computer.

Some of the many applications of computers to these technological problems are listed below:

(i) preparation of torque tables for the design of experimental crane grabs
(ii) analysis of metal fatigue test results
(iii) solution of problems concerned with heat transfer, cooling curves, regenerator theory
(iv) simulation of ground vibrations set up in a hammer forge
(v) determination of the transfer function of an open-hearth furnace
(vi) solution of differential equations concerned with, for example, partial pressure of gases, carbon diffusion, etc.
(vii) calculation of stress/strain relationships and torsion constants for beams
(viii) theoretical calculations concerning electrically heated bodies
(ix) calculation of the thermal balance of the flame smelting process.

#### Mathematical statistics

Probably the most rapid advance in research from the use of computers in the industry has come through the introduction, or the increased use, of statistical methods. Several standard programs, e.g. the Pegasus Multiple Regression Program[10] and the Pegasus Matrix Interpretive Scheme,[11] have eased the programmers' task, and have enabled analyses that would have been prohibitive by manual methods to be completed without delay. Techniques such as curve-fitting, analysis of variance, etc., have become much more widely used in the analysis of experimental data.

Naturally, some difficulties have arisen. From the analysis of blast-furnace performance (for example), although useful estimates of the effects of many variables have been obtained for a single furnace, universally applicable results have not been established. The reasons for this are twofold; one is insufficient accuracy in much of the data available from a works, and the other is inadequacy of the statistical methods of analysis so far employed. Now that the computational capacity is available, the statistician is starting to try more powerful methods, such as component analysis.

#### Operational research

It is significant that of the seven computers in the steel industry, three are installed in OR departments and two other OR groups regularly use the BISRA computer service. Nearly all the work in the application of computers to scientific and technical problems has been done with these machines.

Much of the OR work has been the preliminary statistical analysis of works data. The biggest single class of work is, however, 'simulation', where the computer is made to operate a model of a works or a process to evaluate the merits of one practice or procedure compared with another. Although these experimental calculations take far less time than the processes which they simulate, they still require many hours of computer time, and may eventually demand faster computers.

As with statistical work, standard computer programs have been developed to aid the construction of simulation experiments: Montecode[12] and the General Simulation Program[13] are in constant use. Some simulation experiments have involved participation by works staff; the computer operates the model of a melting shop, for example, and keeps in communication with the staff who decide what actions are to be taken in order to maintain the desired 'production'. In this way it is possible for the staff to try out a proposed new procedure before it is introduced in practice.

There are many other connexions between OR and computers, especially in the realm of decision-making systems. Much of the early work on optimizing cutting losses with the aid of computers was undertaken by OR groups, and currently a number of other on-line applications are being designed.

#### Design and development

The computer is an ideal tool for carrying out standard structural design calculations on a routine basis. Examples of this are the determination of a satisfactory grid of supported floor beams,[5] and the determination of the induced temperature stresses for a given pipework layout with known anchorage position and pipe temperature range.

#### Control and special commercial applications

Digital computers in direct control of processes have not yet been introduced into the British steel industry. Two applications which are allied to this type of work concern ore-digging tactics[6] and how to cut up steel product.[8] Attempts have been made to adapt the techniques of mathematical programming to varying problems, such as the calculation of the material mix

for furnace charging and the determination of order scheduling procedures for a steelworks. Neither of these two projects is yet on a routine practical basis. One company, however, regularly uses a computer each week for planning the details of the following week's production in a melting shop casting bay: complicated arrangements of moulds, ladle nozzles, etc., are worked out so as to meet the required steel-making programme and documents are produced for works use.[14]

Mathematical and statistical techniques now appear in some routine 'commercial' applications, so as to give better managerial control. In a stock-control application, the computer determines when and how much of each commodity to re-order. For production control purposes at another works, a monthly analysis of a sample from production records detects any changes in productivity that may have occurred.

## FUTURE DEVELOPMENTS AND PROBLEMS

Higher speeds, more storage capacity, and smaller physical size, are the main features of computer progress at present. Input and output speeds have also increased. The nature of computers remains essentially the same, however: they may do calculations faster than before, but they still need programming, and we still have to determine how best to apply them in given circumstances. It is safe to say that the next ten years will not see developments sufficiently revolutionary to alter the principles, and problems, of computer applications.

Nevertheless, two particular aspects of computer work are changing drastically: communications to and from the computer, and reliability and accuracy of data recording and transmission. Studies of computer systems for steelworks have shown the necessity for direct communication between shop-floor and computer by push-buttons, by analogue devices, and by electrical signals from production-line machinery, instead of the conventional typewriters, teleprinters, and perforators. The Elliott 803 installation[8] illustrates these developments and it is noteworthy that a very large part of the hardware is concerned with communications.

Data recording is of special interest in research, and already several systems have been developed for producing shop-floor records on punched tape, automatically, and from human observations. These devices, or developments of them, clearly have uses for routine information too, and we expect their use to spread. Automatic transmission of data over long distances is now a practical enterprise; the small-scale use of teleprinter links between Scunthorpe and Sheffield, at only the usual teleprinter speed, has proved successful and much higher speeds are now known to be attainable.

This may affect another matter; the distribution of computers in the industry. If smaller firms are to share computers on a service basis, the communications must be excellent. Scientific and technical calculations and *a fortiori* commercial work, can only be carried out effectively and economically at a distance if delays are avoided and errors are not introduced in transmission.

As an example of what can be done at long distance, a Russian broadcast monitored by the BBC on 23 December 1960 reported that a computer some 300 miles from a steelworks had been linked to a Bessemer shop, and had controlled the making of four heats of steel, including giving instructions as to when to discharge the steel at the end of the heat.

Perhaps the two greatest problems that we face are the supply of trained people to apply computers and the development of the necessary communications equipment. Although programming is becoming easier as manufacturers of computers produce better machines, adopt standard codes, and introduce special 'languages' for many purposes, the tasks of systems analysis and programming, for both technical and commercial work, remain formidable. New computers are being delivered every week in this country: many of the prople to use them have got to be found from within industry, for the supply of recruits from universities and technical colleges cannot possibly be sufficient.

One approach to the problem of building up teams of people with the necessary experience in using computers is to set up staffs to engage in scientific and technical applications to begin with. A large company may consider it worth while to install their own computer for this work, but it is also possible to begin by using the various service bureaux.

The manufacturers of computers are, naturally, mainly concerned with producing general-purpose equipment that will be usable by many industries, and although they have taken a considerable interest in the special needs of the steel industry it is essential that the industry itself should be able to advise them on special requirements. This particularly concerns communications with computers, and equipment which will stand up to the conditions in steelworks. A possible outcome of this co-operation might be the eventual design of a general-purpose information-gathering system, with facilities for distributing and displaying information from the computer to the shop-floor.

It is worth noting that most of the machines so far installed or ordered have been intended *either* for commercial work *or* for scientific work; not usually for both. There seems to be no necessity for this distinction to be a rigid one; computers suitable for both purposes are available, and neither type of work need suffer. The German steel industry, with 12 computers installed and 13 on order, appears to have followed this line successfully.[15,16]

There are about 250 computers installed in this country, of which the steel industry has seven. These numbers are roughly in the same proportion as numbers of people employed: out of a working population of 25 m., about $\frac{1}{2}$ m. are in the steel industry. Each year about 100 new computers are coming into service; the steel industry has three computers on order at present.

## ACKNOWLEDGMENTS

The authors have been greatly assisted by the companies named in this paper who have willingly provided information about their present computer applications and their plans for the future.

## REFERENCES

1. D. G. Owen: 'Computers and steel', 1957, BISRA.
2. *The Computer Bulletin*, 1960, Dec., **4**, 76–79.
3. J. S. Pugh: 'Experience in using a computer for payroll': Computers in the iron and steel industry, 1958, BISRA.

4. *Automation and Automatic Equipment News*, 1960, **6**, 185–189.
5. L. Morgan and W. M. P. Hutson: *JISI*, 1961, **198**, 50–55.
6. H. I. A. Archibald: *ibid.*, **197**, 309–312.
7. C. Ll. Hopkins and M. E. Court: *ibid.*, **198**, 56–62.
8. R. H. Baulk *ibid.*, to be published.
9. R. G. Massey: 'The use of a computer in a rolling mill office': Computers in the iron and steel industry, 1958, BISRA.
10. 'A program for multiple regression analysis', List CS273, Ferranti Ltd, October 1960.
11. 'Matrix interpretive scheme', List CS135, Ferranti Ltd, January 1957.
12. J. N. Buxton and A. E. Head: BISRA Report OR/CA/42/60.
13. K. D. Tocher and D. G. Owen: Proc. 2nd Int. Conf. on operational research, 1960, English Universities Press.
14. P. Brynon: *JISI*, to be published.
15. R. J. Taylor: BISRA Report OR/CA/21/60.
16. R. H. Collcutt *et al.*: BISRA Report OR/CA/74/60.

# Some aspects of airflow through sinter beds

*D. W. Mitchell, B.Sc., A.R.S.M., A.M.I.M.M.*

**SYNOPSIS**

*A knowledge of the relationships existing between the variables involved in the flow of air and combustion products through a sinter bed is of practical importance in design calculations and in appreciating the effect of changes in process conditions on the physical aspects of the operation. The formulae used hitherto in describing the permeability of a sinter bed are compared with other expressions derived for the flow of fluids through granular beds, and their practical implications are examined in the light of experimental observations.* 1962

## VALUE OF 'n' IN THE PERMEABILITY EQUATION

A GENERAL EXPRESSION relating the rate of airflow through a sinter bed to the pressure drop across it was proposed by Voice, Brooks, and Gledhill[1]:

$$P=\frac{F}{A}\left(\frac{h}{s}\right)^n$$

where P is the permeability, F=flow, A=bed area, h=bed height, and s=applied suction; all values being expressed in self-consistent units. The limits of 'n' were given as 1·0 for streamline flow and 0·5 for turbulent flow. With ironstone beds, a variation in the value of 'n' was noted depending on the state of the sintering process:

| | |
|---|---|
| before ignition | n=0·60 |
| immediately after ignition | n=0·65 |
| average during sintering | n=0·60 |
| after complete sintering | n=0·55 |

On this basis, a 'reasonable value' for 'n' of 0·6 was suggested which could be applied over the whole of the sintering process.

Subsequent work by Robertson *et al.*[2] on similar material fixed the value of 'n' at 0·68; this was said to refer to strand gas flow as opposed to windleg flow which includes leakage air. 'n' values for sinter feeds composed of fine grained concentrates, rich ore fines, and ironstone fines were determined by Davies and Mitchell,[3] and it was found that in the airflow–suction range of normal plant practice, 'n' varied from 1·0 for fine-grained concentrates to less than 0·6 for ironstone fines.

### Reynolds number

Changes in the nature of the airflow from streamline to turbulent are thus reflected in changes in the value of 'n'. The more usual criterion used for fluids in motion is the Reynolds number $R$. According to Voice *et al.*[1] typical sinter mixes gave values of $R$ which indicated that the flow was in the transitional range. When applied to fluid flow through granular beds, the Reynolds number can be expressed as:

$$R=\frac{\rho u}{\eta S}$$

where $\rho$=density of fluid, g/cm³, u=apparent velocity of fluid, cm/s, i.e. velocity calculated on empty container, $\eta$=absolute viscosity of fluid, poises, and S=area of particle surface per unit volume of bed, cm²/cm³, i.e. cm⁻¹.

For values of $R<2$ (for solid granular materials) or $<0{\cdot}25$ (for hollow packings)[4] the flow is streamline. Above these values, streamline flow gives way to turbulent flow. Unlike flow through a straight pipe, however, the change takes place gradually and a fully turbulent flow is not reached in fine-grained sand beds until about $R=250$. This has been explained by variations in pore size in the bed,[5] turbulence occurring first in the larger pores, or by an increase in the resistance to flow offered by curved capillaries as against straight capillaries.[6] In either case the relationship between the pressure drop across the bed ($\Delta P$) and the apparent velocity (u) is satisfied by an equation of the form

$$\Delta P=au+bu^m$$

where a, b, and m ($1{\cdot}6<m<2{\cdot}0$) are constants characteristic of the bed. In effect, this equation represents the combination of streamline flow ($\Delta P=au$) with turbulent flow ($\Delta P=bu^m$).

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The work described in this paper was carried out at the Swinden Laboratories of the United Steel Companies Ltd. The author is now with the Park Gate Iron and Steel Co. Ltd.

**TABLE I Comparison of 'n' and $R$ for sinter feed**

| 'n' | $R$ Ironstone fines, <¼in | Rich ore fines, <¼in | Medium grained concentrates, <¼in |
|---|---|---|---|
| 0·95 | ... | 1·2 | 0·5 |
| 0·90 | 3·7 | 1·6 | 0·7 |
| 0·85 | 4·7 | 2·0 | 1·3 |
| 0·80 | 5·4 | 2·4 | ... |
| 0·75 | 6·2 | 3·0 | ... |
| 0·70 | 6·8 | 3·5 | ... |
| 0·65 | 7·3 | 4·0 | ... |
| 0·60 | 7·9 | ... | ... |

### Carman's equation

An equation of this type was developed by Carman,[7] who applied Blake's method of plotting dimensionless groups[8] and established an empirical relationship between $R$ and a friction factor

$\frac{\Delta P\, g\, \epsilon^3}{L\rho u^2 S_1}$ denoted by $\psi$ in the form

$$\psi = 5\left(\frac{\eta S}{\rho u}\right) + 0{\cdot}4\left(\frac{\eta S}{\rho u}\right)^{0{\cdot}1}$$

where $(\eta S/\rho u) = 1/R$, g=acceleration due to gravity (981 cm/s²), $\epsilon$=voidage (fractional free volume), L=bed depth, cm, $S_1$=total surface area per unit volume of bed, including wall surface, cm²/cm³. This equation was in reasonable agreement with published experimental data for the flow of both gases and liquids through a variety of bed materials including spheres, wire spirals, and porcelain saddles, and covered values of $R$ from 0·01 to 10000. In a sinter bed, where the wall surface is very small relative to the particle surface area, $S_1$ can be assumed equal to S.

Where flow is streamline, the second term of this equation is negligible, and where flow is turbulent, the first term is negligible. Thus for streamline flow, the expression may be written as

$$\frac{\Delta P\, g\, \epsilon^3}{L\rho u^2 S} = 5\,\frac{\eta S}{\rho u}$$

or

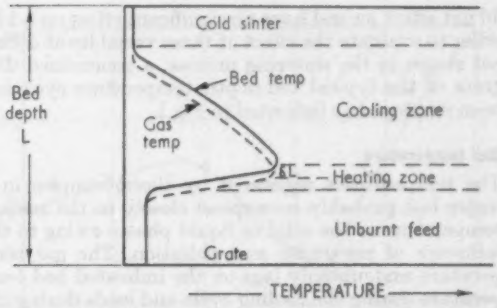
$$\frac{g\,\epsilon^3}{5\eta S^2} = u\frac{L}{\Delta P}$$

This is the permeability equation of Voice *et al.*[1] for streamline flow where 'n'=1, L/ΔP is equivalent to h/s and u is equivalent to F/A. The make-up of the 'permeability' term on the left-hand side of the equation is of interest in that its value for a given sinter bed depends on the viscosity of the gas passing through it ($\eta$), the particle surface area (S), and the voidage ($\epsilon$): factors which change in the course of sintering. Similarly, for turbulent flow, from

$$\frac{\Delta P\, g\, \epsilon^3}{L\rho u^2 S} = 0{\cdot}4\left(\frac{\eta S}{\rho u}\right)^{0{\cdot}1}$$

$$\frac{g\epsilon^3}{0{\cdot}4\eta^{0{\cdot}1} S^{1{\cdot}1} \rho^{0{\cdot}9}} = u^{1{\cdot}9}\frac{L}{\Delta P}$$

This suggests that the value of 'n' in the equation of Voice *et al.* for turbulent flow is 1/1·9 or 0·526. In recent work performed by the author on the air-cooling of broken sinter in turbulent flow conditions, an 'n' value of 0·53 was obtained. Similar tests reported by Voice, Brooks, Davies, and Robertson[9] led to the assumption of 'n'=0·55, although individual results varied between 0·50 and 0·57. The work of Forchheimer[5] suggests that the value of 'n' for turbulent flow may in certain cases be as much as 0·625.




**1** *Generalized diagram of typical bed depth–temperature cycle*

## CORRELATION OF REYNOLDS NUMBER WITH 'n' FOR SINTER FEED

Calculations of $R$ and 'n' have been made from experimental observations on various sinter feeds. The results are presented in Table I. Determinations of S for use in the Reynolds number calculations were based on the method of Lea and Nurse.[10]

It is clear that there is no general correlation between 'n' and $R$ which applies to all types of sinter feed. As noted by other workers, the empirical relationships change slightly from one material to another, and provision is made for this in equations which attempt to be comprehensive.[5] The critical $R$ value where departure from streamline flow begins is less for the sinter feed of smaller particle size. The range is small, however, and may be said to conform to the accepted standards.[4]

With the coarse ironstone feed, large increases in airflow to values beyond those normally encountered in sintering (up to 300 ft³/ft²/min) failed to reduce 'n' to <0·55, and similarly with the slightly smaller rich ore fines to <0·60. Medium grained concentrate feed showed a more gradual change in 'n' over the range of airflow used, this effect being more pronounced for fine grained concentrates. It is probable that the transitional region from streamline to fully turbulent flow is much less extensive for the more coarsely sized sinter feed, and that in these cases, fully turbulent flow exists at normal sintering airflows for 'n' values of about 0·6. The straight line relationships obtained by Voice *et al.*[1] for log plots of airflow against suction and bed height, giving constant 'n' values of 0·6 and 0·62 respectively, certainly suggest that this is so. In these coarsely sized sinter feeds, the pores through which the air passes are relatively large in cross-section and the change from streamline to turbulent flow becomes more analogous to the sudden transition experienced in flow through pipes.

With concentrate sinter feed, normal sintering airflows lie in the transitional region and changes in $R$ are indicative of changes in the nature of the flow and hence of 'n'.

## CHANGES DURING SINTERING WHICH AFFECT REYNOLDS NUMBER

All the quantities used to calculate $R$ $(=\rho u/\eta S)$ are subject to change during sintering. These changes are effected by variations in gas composition and temperature, in the rate of gas flow, and by the change in particle surface area resulting from the conversion of feed to sinter. (Changes in absolute pressure in the bed

do not affect $\rho u$ and have no significant effect on $\eta$.) In order to evaluate the effect of these variables at different stages in the sintering process, a generalized diagram of the typical bed depth–temperature cycle has been employed as indicated in Fig.1.

### Gas temperature

The temperatures registered by thermocouples in a sinter bed probably correspond closely to the surface temperature of the solid or liquid phases owing to the influence of proximity and radiation. The gas temperature undoubtedly lags on the indicated bed temperature during the cooling cycle and leads during the heating cycle. If the process is regarded simply as a heat-transfer mechanism of the temperature cycle through the sinter bed,[3,11] Newtonian principles would indicate equality between bed and gas temperatures provided a constant maximum bed temperature is maintained. When in practice the process is sustained by progressive carbon combustion, brought about by heat transfer, the internal generation of heat is ideally only sufficient to balance the losses. The form of the gas temperature curve will depend upon the efficiency of heat transfer from phase to phase, but estimation of transfer coefficients in the complex changing system of the flame front is virtually impossible. For the purpose of a first approximation and in the absence of reliable gas temperature data, a simple displacement ($\delta$L) is assumed (Fig.1), small relative to the bed depth (L).

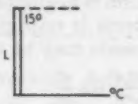
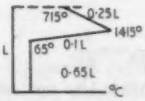
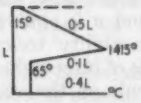
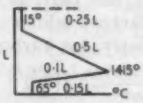
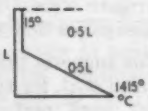
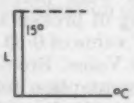
### Gas composition

Changes in gas composition in this context are important only in their effect on gas density and viscosity. There is obviously no addition to the incoming air until the heating cycle is reached. In this zone and in the unburnt feed, $H_2O$, $CO_2$, and CO are present as well as $O_2$ and $N_2$.[12] The relative quantities of each gas will depend on the nature of the sinter feed, the fuel content, moisture content, and other factors of less consequence.

In an ironstone sinter bed, where volatile, fuel, and moisture contents are relatively high, the ratio of $N_2$ to other gases in the exit gas will be at a minimum. For example, from 1 ton of a typical sinter mixture prepared from Northants and Frodingham ironstones and containing 40% returned fines, the following gas volumes (at STP, i.e. 60°F, 30in Hg) would be generated:

| | ft³ |
|---|---|
| free $H_2O$ | 4700 |
| combined $H_2O$ | 1600 |
| $CO_2$ from carbonate | 1600 |
| $CO_2$ from fuel, assuming 4:1 $CO_2$:CO ratio | 2300 |
| CO | 600 |

**TABLE II Data used for $R$ calculations**

| | Gas density at STP, g/cm³ | Air velocity at STP, cm/s | Average gas temp., T°C | Gas viscosity at T°C, poises | Particle surface area (S), cm²/cm³ | Position of temperature cycle in relation to bed depth (L) |
|---|---|---|---|---|---|---|
| *Pre-ignition* | $1{\cdot}23\times10^{-3}$ | 25 | 15 | $178\times10^{-6}$ | 68 |  |
| *¼-sintered* | | | | | | |
| Cooling zone | $1{\cdot}23\times10^{-3}$ | 13·5 | 1065 | $500\times10^{-6}$ | 21 |  |
| Heating zone | $1{\cdot}21\times10^{-3}$ | 16·5 | 740 | $420\times10^{-6}$ | 46 | |
| Unburnt feed | $1{\cdot}19\times10^{-3}$ | 20 | 65 | $185\times10^{-6}$ | 68 | |
| *½-sintered* | | | | | | |
| Cooling zone | $1{\cdot}23\times10^{-3}$ | 13·5 | 715 | $400\times10^{-6}$ | 21 |  |
| Heating zone | $1{\cdot}21\times10^{-3}$ | 16·5 | 740 | $420\times10^{-6}$ | 46 | |
| Unburnt feed | $1{\cdot}19\times10^{-3}$ | 20 | 65 | $185\times10^{-6}$ | 68 | |
| *¾-sintered* | | | | | | |
| Cold sinter | $1{\cdot}23\times10^{-3}$ | 17·5 | 15 | $178\times10^{-6}$ | 21 |  |
| Cooling zone | $1{\cdot}23\times10^{-3}$ | 17·5 | 715 | $400\times10^{-6}$ | 21 | |
| Heating zone | $1{\cdot}21\times10^{-3}$ | 22 | 740 | $420\times10^{-6}$ | 46 | |
| Unburnt feed | $1{\cdot}19\times10^{-3}$ | 26·5 | 65 | $185\times10^{-6}$ | 68 | |
| *Sintered* | | | | | |  |
| Cold sinter | $1{\cdot}23\times10^{-3}$ | 30 | 15 | $178\times10^{-6}$ | 21 | |
| Cooling zone | $1{\cdot}23\times10^{-3}$ | 30 | 715 | $400\times10^{-6}$ | 21 | |
| *Cold sinter* | $1{\cdot}23\times10^{-3}$ | 30 | 15 | $178\times10^{-6}$ | 21 |  |

Notes: Gas densities from standard tables. Air velocities from experimental observations and estimated gas composition. Average gas temperature from generalized temperature cycle based on experimental observations. Gas viscosities from Perry,[4] 370, 371. Particle surface areas from experimental observations based on the method of Lea and Nurse.[10]

**TABLE III Comparison of 'n' and $R$ during sintering**

| State of sinter bed | $R$ | Average, $R$ | 'n' |
|---|---|---|---|
| *Cold feed* | | | |
| Pre-ignition | 2·5 | 2·5 | 0·8 |
| *¼-sintered* | | | |
| Cooling zone (0·25 L) | 1·6 | | |
| Heating zone (0·1 L) | 1·0 | 1·7 | 0·83 |
| Unburnt feed (0·65 L) | 1·9 | | |
| *½-sintered* | | | |
| Cooling zone (0·5 L) | 2·0 | | |
| Heating zone (0·1 L) | 1·0 | 1·9 | 0·85 |
| Unburnt feed (0·4 L) | 1·9 | | |
| *¾-sintered* | | | |
| Cold sinter (0·25 L) | 5·8 | | |
| Cooling zone (0·5 L) | 2·6 | 3·3 | 0·75 |
| Heating zone (0·1 L) | 1·4 | | |
| Unburnt feed (0·15 L) | 2·5 | | |
| *Sintered* | | | |
| Cold sinter (0·5 L) | 9·9 | 7·2 | 0·7 |
| Cooling zone (0·5 L) | 4·4 | | |
| *Cold sinter* | 9·9 | 9·9 | 0·65 |

The total volume of incoming air/ton of sinter feed is normally about 25000 ft³. Of this volume, 2600 ft³ of $O_2$ are consumed in fuel combustion, leaving 2400 ft³ in the exit gas. Assuming that no change occurs in the degree of oxidation of the iron in converting ore to sinter, the $N_2$ content of the exit gas is about 20000 in 33200 ft³.

While there is no completely satisfactory method for calculating the viscosity of gas mixtures, an approximation to within 5–10% can be made by means of Mann's formula,[13]

$$\frac{1}{\nu}=\frac{n_1}{\nu_1}+\frac{n_2}{\nu_2}+\ldots$$

where $\nu$=kinematic viscosity of the mixture ($cm^2/s^{-1}$) $=\eta/\rho$; $n_1$, $n_2$=mole fractions of the individual constituents 1, 2, etc. Gas density is an additive property, so that

$$\rho=n_1\rho_1+n_2\rho_2+\ldots$$

Applying these functions to the ironstone example given above, the density and viscosity of the exit gas (at STP) would be as follows:

| | $\rho$ g/cm³ | $\eta$ poises |
|---|---|---|
| Ironstone feed | $1{\cdot}20\times10^{-3}$ | $166\times10^{-6}$ |
| (*cf.* air) | $1{\cdot}23\times10^{-3}$ | $178\times10^{-6}$ |

These values may be applied to the gas passing through the unburnt feed and an intermediate value taken for the heating zone where the gases are generated as the temperature progressively increases.

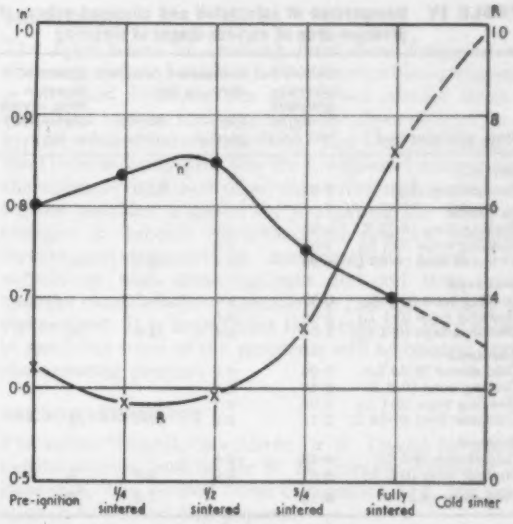
For concentrate and rich ore feeds, the differences between air and exit gas constants are of the same order, typical values being as follows:

| | $\rho$ g/cm³ | $\eta$ poises |
|---|---|---|
| Concentrate feed | $1{\cdot}19\times10^{-3}$ | $167\times10^{-6}$ |
| Rich ore feed | $1{\cdot}18\times10^{-3}$ | $166\times10^{-6}$ |
| (*cf.* air) | $1{\cdot}23\times10^{-3}$ | $178\times10^{-6}$ |

The variation of $\eta$ with temperature can be determined from Sutherland's formula, which has been found to apply with some accuracy in similar circumstances,[14] or from tables given by Perry.[4]

### Gas flow

Changes in the rate of flow both into and from the sinter bed can be determined experimentally or deduced from a knowledge of one of the flow rates and the exit gas composition. The heating cycle is again a transitional zone for which an intermediate value must be assumed.




**2** *Comparison of 'n' and* R *during sintering*

### Particle surface area

Specific surface determinations can be performed on the feed and the resultant sinter *in situ* when using an experimental sinter box equipped to measure low airflows. With specific ores or sinter feeds, some correlation is possible with the size grading. In general, the particle surface area/unit bed volume is less for sinter than for feed, and it is assumed that an intermediate value applies to the feed in process of conversion to sinter in the heating zone.

## CORRELATION OF REYNOLDS NUMBER WITH 'n' DURING SINTERING

Calculations of $R$ during sintering have been made for a sinter bed composed of concentrate feed agglomerates, including 20% returned fines and 5% coke breeze, lime-coated to prevent bed collapse during sintering. The data used for the calculations are shown in Table II. A generalized temperature cycle based on actual bed temperature observations from numerous repetitive tests has been used to estimate average gas temperatures and is included in Table II to represent the various stages in sintering to which the data apply. Experimental determinations of 'n' have been made before, during, and after sintering, and are compared with the Reynolds numbers in Table III. The results are presented graphically in Fig.2.

For a sinter bed of this type, a good inverse correlation is obtained between $R$ and 'n' covering the whole of the sintering process. A slight discrepancy occurs in the relative $R$ values for ¼- and ½-sintered, and this can be attributed to a small gain in energy of the heat wave observed as sintering progressed compared with the constant value represented by the assumed bed temperature cycle. Evidently, the airflow is in the transitional region between streamline and turbulent throughout. For a coarsely sized ironstone sinter bed, where flow is fully turbulent at the start of sintering, changes in $R$ will not affect 'n' unless or until the transitional region is reached.

The data presented above indicate the relative importance of the variables affecting the nature of the

**TABLE IV Comparison of calculated and observed values of pressure drop at various stages of sintering**

| State of sinter bed | Calculated pressure gradient in wg/in bed depth | Calculated pressure drop, in wg | | Observed pressure drop across sinter bed, in wg |
|---|---|---|---|---|
| | | Component | Across sinter bed | |
| *Cold feed* | | | | |
| Pre-ignition (L) | 2·13 | | 25·6 | 25 |
| *¼-sintered* | | | | |
| Cooling zone (0·25 L) | 0·52 | 1·6 | | |
| Heating zone (0·1 L) | 3·02 | 3·6 | | |
| Unburnt feed (0·65 L) | 1·96 | 15·3 | 20·5 | 20 |
| *½-sintered* | | | | |
| Cooling zone (0·5 L) | 0·32 | 1·9 | | |
| Heating zone (0·1 L) | 3·02 | 3·6 | | |
| Unburnt feed (0·4 L) | 1·96 | 9·4 | 14·9 | 18 |
| *¾-sintered* | | | | |
| Cold sinter (0·25 L) | 0·06 | 0·2 | | |
| Cooling zone (0·5 L) | 0·43 | 2·6 | | |
| Heating zone (0·1 L) | 3·94 | 4·7 | | |
| Unburnt feed (0·15 L) | 2·72 | 4·9 | 12·4 | 15 |
| *Sintered* | | | | |
| Cold sinter (0·5 L) | 0·13 | 0·8 | | |
| Cooling zone (0·5 L) | 0·81 | 4·9 | 5·7 | 8 |
| *Cold sinter* (L) | 0·13 | | 1·6 | 2 |

air or gas flow during sintering. Those having the greatest influence are the rate of airflow (u), the ratio of the particle surface area (S) of the unburnt feed to that of sinter, and the integrated bed temperature in its effect on gas viscosity ($\eta$). The numerator of the $R$ expression is not affected by temperature since the product of $\rho$ and u is in terms of mass/unit area/unit time. Of relatively minor importance is the effect of changes in gas composition on $\rho$ and $\eta$. In sinter strand operation it is the average value of 'n' over the whole of sintering ($n_{Av}$) which is of practical importance in fan power calculations, etc. The weighted average of batch tests should take into account changes in the sintering rate during sintering. In the tests represented above, this was nearly constant and $n_{Av}=0{\cdot}80$. Thus, as in the case of the tests referred to by Voice *et al.*,[1] $n_{Av}$ is the same as the pre-ignition value of 'n'.

At this point, some general observations can be made from a comparison of $R$ and the index 'n' of the permeability equation for different sinter feeds and at various stages in the sintering process:

(i) the limiting value of 'n' when flow is fully turbulent is >0·5
(ii) the value of 'n' for turbulent flow increases with decrease in the size of particle agglomerates
(iii) the extent of the transitional region in terms of $R$ between streamline and fully turbulent flow increases with decrease in the size of particle agglomerates
(iv) the value of $R$ changes during sintering, decreasing in the tests described above over roughly the first one-third and increasing over the remaining two-thirds of the cycle. If airflow is in the transitional region, changes in $R$ indicate inverse changes in 'n', but with a coarsely sized sinter feed fully turbulent conditions may exist at normal sintering rates of flow and changes in $R$ do not affect the value of 'n' unless the transitional region is reached.

### Calculation of pressure drop

Using the data given in Tables II and III supplemented by experimental determinations of voidage ($\epsilon$), calculations of pressure drop across the sinter bed may be made from the Carman relationship

$$\frac{\Delta P}{L}=\frac{\rho u^2 S}{g.\epsilon^3}\left[5\left(\frac{1}{R}\right)+0{\cdot}4\left(\frac{1}{R}\right)^{\cdot 1}\right]$$

For the concentrate feed agglomerate used in the tests, $\epsilon=0{\cdot}39$, and for the sinter, $\epsilon=0{\cdot}53$. An assumed value of $\epsilon=0{\cdot}46$ has been taken for feed in the process of conversion to sinter in the heating zone. The bed height (L) in these tests was 12in. The calculated values of pressure drop at each stage of the process deduced from the Carman relationship, are compared with the observed values in Table IV.

Having regard to the assumptions made, the agreement between calculated and observed values is remarkably good. The discrepancies could be accounted for by variation in practice from the assumed bed-temperature cycle. Departure from the generalized form used for the calculations increases as sintering proceeds with the development of a thicker hot zone with which high pressure gradients are associated. At peak bed temperature, the calculated pressure gradient for ¾-sintered is of the order of 3·5inwg/in bed depth. Thus any extension of the heating zone or prolongation of the peak temperature in terms of bed depth implies a marked increase in pressure drop. This feature of the process has been demonstrated experimentally by Grice and Davies.[15] It is clearly advantageous to restrict the hot zone to the minimum required for adequate fusion.

### Correlation with sintering rate

Heat transfer considerations enable a simple estimate to be made of sintering air requirements. The movement of the temperature cycle, as depicted in Fig.1, through the sinter bed is achieved by transfer of heat from the cooling sinter in the cooling zone to the air passing through it and thence to the feed in the heating zone.[3,11] In the ideal case, where the form of the temperature cycle is unchanged throughout the process, the total air volume is equivalent to the mass of air required to absorb the heat in the cooling sinter, provided that the quantity of air used to introduce the cycle from the external heat source (e.g. ignition burners) is the same as that used in its propagation through the bed.

Ideally, air per ton of sinter is given by

$$C_{air}M_{air}\,(T_2-T_1)=C_{sinter}.2240\,(T_2-T_1)$$

where $C_{air}$=specific heat of air over temperature range $T_1-T_2$, $C_{sinter}$=specific heat of sinter over temperature range $T_1-T_2$, and $M_{air}$=lb of air/ton of sinter. Hence

$$M_{air}=\frac{C_{sinter}}{C_{air}}\,.\,2240\text{ lb}$$

$$=\frac{0{\cdot}22}{0{\cdot}26}\,.\,2240\text{ lb}$$

or

25000 ft³ at STP.

It is of interest that this quantity is independent of temperature except in so far as changes in the temperature range affect the specific heats of air and sinter.

The volume of air (ft³ at STP) per ton of sinter feed, sometimes referred to as the 'specific air volume', can be deduced from air/ton of sinter by allowing for the volatile loss during sintering. Similarly, the waste gas volume/ton of sinter feed, or 'specific waste gas volume' can be deduced from a knowledge of the exit gas composition. Typical values are given below:

| Sinter feed | Specific air volume, ft³ at STP | Specific waste gas volume, ft³ at STP |
|---|---|---|
| ironstone fines | 17500 | 27000 |
| rich ore fines | 21000 | 30000 |
| concentrates | 22500 | 31000 |

In practice, heat transfer becomes less efficient with increasing airflow rates and, as noted elsewhere,[3, 12] this leads to some increase in the total air requirement.

The relationship between the sintering rate and the air required for sintering can be expressed in terms of the apparent gas velocity (u) used in the calculations of pressure drop. Depending on the units adopted, sintering rate equals

$$\frac{2240 \times 23{\cdot}6\, u_1}{\text{sp. air vol} \times \beta} \text{ in/min}$$

or

$$\frac{2240 \times 23{\cdot}6\, u_2}{\text{sp. waste gas vol} \times \beta} \text{ in/min}$$

where $u_1$ is the inlet air velocity (STP) in cm/s, $u_2$ is the exit gas velocity (STP) in cm/s, and $\beta$ is the bulk density of the sinter feed in lb/ft³.

Taking the second expression and the derived value of 31000 ft³/ton for the specific waste gas volume of the concentrate sinter feed used in the worked example above, sintering rate equals

$$\frac{1{\cdot}71}{\beta} u_2.$$

The bulk density in this case was 125 lb/ft³ and the average exit gas velocity about 24 cm/s (*see* Table II). Substituting these values in the above expression, sintering rate becomes 0·33in/min, and the sintering time for a 12in bed about 36 min. This calculated value compares closely with the observed values (i.e. time to maximum waste gas temperature) for the tests performed on this feed, all in the range 34–38 min.

## CONCLUSION

The application of existing fluid flow formulae to sintering airflow has shown that reasonable agreement is obtained between the calculated results from a simplified system and experimental observations on a typical concentrate sinter bed. The Carman formula used in evaluating pressure drop, while not necessarily the ultimate definition of air-flow relationships, nevertheless provides a model for evaluating the effect of changes in process variables and renders possible further development on mathematical lines. The correlation with sintering rate deduced from heat transfer considerations extends the practical utility of the method. It is hoped that this approach may assist in resolving some of the problems still associated with the sintering process.

## ACKNOWLEDGMENTS

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## REFERENCES

1. E. W. Voice, S. H. Brooks, and P. K. Gledhill: *ISI Spec. Rep.* 53, 1955.
2. B. L. Robertson *et al.*: *2nd Symposium on iron ore sintering*, 1957, Paris.
3. W. Davies and D. W. Mitchell: 'Developments in sintering efficiency'; Int. Mineral Dressing Congress, 1957, Stockholm.
4. John H. Perry: Chemical engineers handbook; section 5, 1950, 3rd ed.
5. P. Forchheimer: Hydraulik; 1930, 3 Aufl.
6. J. Chalmers *et al.*: *Trans. AIME*, 1932, **98**, 375.
7. P. C. Carman: *Trans. I.Chem.E.*, 1937, **15**, 150.
8. F. C. Blake: *Trans. Am.I.Chem.E.*, 1922, **14**, 415.
9. E. W. Voice, S. H. Brooks, W. Davies, and B. L. Robertson: *ISI Spec. Rep.* 53, 1955.
10. F. M. Lea and R. W. Nurse: *J. Soc. Chem. Ind.*, 1939, **58**, 277.
11. E. W. Voice and R. Wild: *AIMM and Pet. Eng., Blast Furn. Conf.*, 1957.
12. J. Michard: 2nd Symposium on iron ore sintering, 1957, Paris.
13. V. Mann: *Gas und Wasserfach*, 1930, **73**, 570.
14. P. Bremond: *Trans. Ceram. Soc.*, 1934–35, **34**, 287.
15. M. A. K. Grice and W. Davies: *ISI Spec. Rep.* 53, 1955.

# On the mechanism of yielding and flow in iron

*Hans Conrad*


## SYNOPSIS

*The activation energy, activation volume, and frequency factor have been evaluated for yielding (delay time for yielding, upper yield stress, lower yield stress, and Lüders band propagation) and flow (friction stress, flow stress, and dislocation mobility) for various irons and steels from data in the literature. It was found that the values of these flow parameters and their stress dependence were the same, within experimental error, for both yielding and flow and for all the materials considered. This suggests that either the same dislocation mechanism is controlling in every case or that one or more mechanisms possess about the same values for these parameters. The dislocation mechanism for which there was closest agreement between theoretical calculations and experimental data was overcoming the Peierls stress.*

*On the basis of the available experimental data and the present analysis it is suggested that the upper and lower yield stresses in iron and steel may represent the sudden generation of a large number of dislocations by the double cross-slip mechanism of Koehler and Orowan rather than the breaking away from a Cottrell atmosphere.*

1950


## INTRODUCTION

EXPERIMENTAL INVESTIGATIONS on yielding and flow in iron have established that (i) discontinuous yielding (i.e. the upper and lower yield points) are associated with the presence of carbon and nitrogen[1–3] and (ii) the effect of grain size on the upper yield stress,† $\sigma_{uy}$, the lower yield stress $\sigma_{ly}$, and the flow stress $\sigma_{fl}$ subsequent to yielding is given by an equation of the form[4–8]

$$\sigma = \sigma_i + k^* d^{-\frac{1}{2}} \quad \ldots\ldots(1)$$

where $d$ is the average grain diameter and $k^*$ is a constant. $\sigma_i$ is termed the friction stress and consists of two parts: an athermal component $\sigma_i$ $(st)$ which depends only on the structure $st$ (for example, precipitates, C+N in solution, etc.) and a thermal component $\sigma_i^*$ which depends sensitively on temperature and strain rate. Equation (1) may thus be written

$$\sigma = \sigma_i^* + \sigma_i(st) + k^* d^{-\frac{1}{2}} \quad \ldots\ldots(2)$$

Interpretation of the observed mechanical behaviour during yielding and flow of iron in terms of dislocation theory is mainly due to Cottrell[9, 10] and Petch.[5, 11] Their explanation is as follows: owing to the elastic interaction between carbon and nitrogen and dislocations in iron, these interstitials segregate to the dislocations and lock them. During the initial loading of a specimen below the upper yield stress, some dislocations are torn from their interstitial atmosphere at regions of stress concentration, for example at $S_1$, and act as sources for the generation of additional dislocations. The newly generated dislocations then move along the slip plane and pile up at some strong obstacle, such as a grain boundary, where they exert a stress concentration, whose value a distance $l$ ahead of the pile-up is given by $(\sigma - \sigma_i)(d/2l)^{\frac{1}{2}}$. Here $\sigma$ is the applied stress, $d$ is the grain diameter, and $\sigma_i$ represents the resistance of the lattice to the motion of dislocations from $S_1$ to the grain boundary. Yielding occurs at $S_2$ (the location of another locked dislocation in the next grain a distance $l$ from the boundary) when the total stress there is sufficient to tear the dislocation from its atmosphere. If $\sigma_l$ is the unlocking stress at $S_2$, one may write

$$(\sigma - \sigma_i)(d/2l)^{\frac{1}{2}} + \sigma = \sigma_l \quad \ldots\ldots(3)$$

and if $d \gg l$ this becomes

$$\sigma = \sigma_i + (2l)^{\frac{1}{2}} \sigma_i d^{-\frac{1}{2}} \quad \ldots\ldots(4)$$

which is identical to equation (1) with $k^* = (2l)^{\frac{1}{2}}\sigma_i$.

The motion of dislocations from $S_1$ to the grain boundary can then account for the commonly observed pre-yield microstrain,[12–14] and the yielding at $S_2$ is identified with the upper yield stress, i.e. the formation of the initial Lüders band.‡ The lower yield stress is then a propagation of the Lüders band and in essence is a repetition of the above process along the band front. To explain that a lower stress is required to propagate a Lüders band as compared to its initiation, it is assumed that a higher stress concentration§

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† In the present paper $\sigma$ indicates the tensile stress. The shear stress along the slip plane will be designated by $\tau$, and it will be assumed that $\tau = \sigma/2$.

‡ This initial Lüders band generally occurs in the vicinity of the grips or other regions of stress concentration, hence the experimental values of $\sigma_i$ and $\sigma_l$ of equation (4) for the upper yield stress may be lower than the true values by a factor representing the stress concentration.

§ Consequently the experimental values of $\sigma_i$ and $\sigma_l$ for the lower yield stress will be even less than the corresponding values for the upper yield stress.

occurs at the band front than existed at the site of initial yielding and that there are more places where the unlocking can occur.

The flow stress for strains beyond the Lüders strain is associated with the motion of dislocations free of their atmosphere. It is anticipated that this motion is governed by the same mechanism as that giving the friction stress $\sigma_i$ in yielding.

Strain-ageing occurs when a strained specimen is heated to a sufficiently high temperature that interstitial diffusion reforms atmospheres about the 'free' dislocations. Serrated stress–strain curves result when strain-ageing occurs during deformation; i.e. when the strain-rate and temperature are such that initially a dislocation is torn from its atmosphere, only to regain it later as the dislocation is temporarily held up at some obstacle.

Equations (1) and (4) indicate that the temperature dependence of the yield stress represents the combined temperature dependence of the friction stress $\sigma_i$ and locking stress $\sigma_l$. Cottrell and Bilby,[15] Fisher,[16] and Cottrell[17] have shown that one can expect a strong temperature dependence for $\sigma_l$, comparable to that observed for the lower yield stress. No complete theoretical evaluation has as yet been made for the temperature dependence of $\sigma^*_i$. However, a strong temperature dependence is observed experimentally for this parameter and it has been suggested that $\sigma^*_i$ may be due to a high Peierls stress[18] or due to the movement of jogs in screw dislocations.[19]

The above discussion indicates considerable agreement between the experimental observations and the theoretical model. However, there exist certain experimental facts which are not in complete accord with theory. These are:

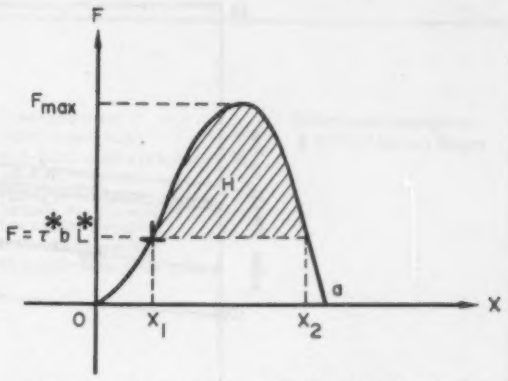
(i) the constant $k^*$ of equation (1) for the lower yield stress is relatively independent of temperature from 300°K to about 120°K.[8,20,21] Since $k^*$ is a measure of the unlocking stress, this is not expected from the theoretical analyses[15–17] of the breaking-away from an atmosphere.

(ii) the value of $k^*$ is about the same for the flow stress, representing the motion of 'free' dislocations, as for the lower yield stress[7, 8]

(iii) the friction stress $\sigma_i$ obtained for mild steel by extrapolation to zero concentration of carbon plus nitrogen *in solution*[18] has a stronger temperature dependence than the flow stress for zone refined iron[22, 23]

(iv) for a given *total* carbon plus nitrogen concentration, the temperature dependence of the lower yield stress for polycrystalline samples extrapolated to infinite grain size is stronger than that for single crystals.[23]

These discrepancies between theory and experiment indicate that our understanding of the dislocation mechanisms which control yielding and flow in iron is still inadequate. One aspect which has not been previously explored in detail is to evaluate such atomic parameters as the frequency factor, the activation energy and the activation volume for yielding and flow from mechanical test data and compare these with predictions of specific dislocation models. Consequently, this was undertaken in the present paper. Since considerable mechanical test data of value could be found in the literature, it was decided to use these data rather than initiate a new experimental program.†




1 *Schematic of the force–distance relationship for yielding or flow of iron*

## DEFORMATION EQUATIONS

It is now generally accepted that the deformation of metals may be thermally activated and that if a single deformation mechanism is controlling the strain rate $\dot{\gamma}$ is given by

$$\dot{\gamma}=\nu e^{-H/kT} \quad \ldots\ldots(5)$$

where $\nu$ is a frequency factor which includes essentially the frequency of vibration, the number of places where activation can take place, and the strain per successful fluctuation; $H$ is the enthalpy of activation, which may be a function of stress and/or temperature, and can be obtained from yield and flow stress data by the following equations[24]:

$$H=-kT^2\left\{\frac{\left(\frac{\partial\tau^*}{\partial T}\right)_{\dot{\gamma}}}{\left(\frac{\partial\tau}{\partial\ln\dot{\gamma}/\nu}\right)_T}\right\} \quad \ldots\ldots(6)$$

or

$$H=-k\left(\frac{\partial\ln\dot{\gamma}/\nu}{\partial 1/T}\right)_{\tau^*} \quad \ldots\ldots(6a)$$

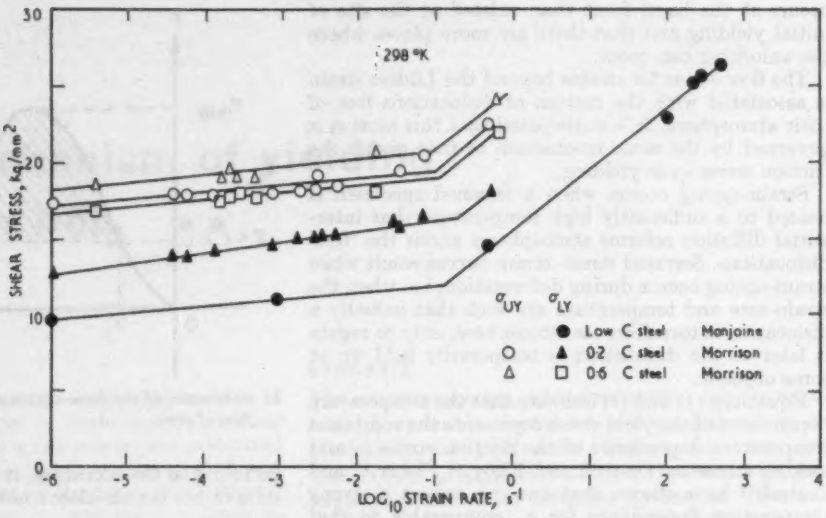
where $\tau^*=\tau-\tau_\mu$ is the effective stress, i.e. $\tau^*$ is the difference between the applied shear stress $\tau$ and the long range internal shear stress $\tau_\mu$, the latter being proportional to the shear modulus $\mu$. $\tau^*$ is frequently termed the thermal component of the stress.

One expects that the force–distance relationship for thermally activated yielding or flow is of the general form shown in Fig.1. Hence, for a given value of stress $\tau^*$, a dislocation will take the position $x_1$ and the energy $H$ which must be supplied by thermal fluctuations is given by the shaded area. One can therefore write equation (5) as:

$$\dot{\gamma}=\nu e^{-\left\{\frac{H^*-v^*\tau^*}{kT}\right\}} \quad \ldots\ldots(7)$$

where $H^*$ is the total area under the force–distance curve between $x_1$ and $x_2$ and $v^*\tau^*=b\ L^*\ (x_2-x_1)\ \tau^*$ is the work done by the stress during the thermal activation. $b$ is the Burgers vector, and $L^*$ is the length of the dislocation segment involved in the

† Some unpublished data by the author are also included.




**2** *Variation of the upper yield stress $\sigma_{uy}$ and the lower yield stress $\sigma_{ly}$ with strain rate at 298°K*

activation. $v^*=b\,L^*\ (x_2-x_1)$ is the 'activation volume'.

If the total energy to overcome the obstacle to flow (i.e. the total area under the force–distance curve) is not a function of stress, one can obtain the value of $v^*$ in the following manner: from Fig.2 we note that $H$ can be expressed as

$$H=\int_{F=\tau^* bl}^{F_{max}} [x_2(F)-x_1(F)]\,dF \qquad (8)$$

which gives upon differentiation with respect to $\tau^*$

$$-\left(\frac{\partial H}{\partial \tau^*}\right)_T=(x_2-x_1)bL^*=v^* \qquad (9)$$

Furthermore, from equation (5) we obtain

$$-\left(\frac{\partial H}{\partial \tau^*}\right)_T=kT\left(\frac{\partial \ln \dot{\gamma}/\nu}{\partial \tau^*}\right)_T \qquad (10)$$

and combining equations (9) and (10) gives‡

$$v^*=kT\left(\frac{\partial \ln \dot{\gamma}/\nu}{\partial \tau^*}\right)_T \qquad (11)$$

In the above we have derived equations for the activation energy and the activation volume for a particular deformation mechanism. Of additional interest is an evaluation of the frequency factor $\nu$. This can be obtained from the slope of a plot of $H$ *v.* temperature, for upon taking the logarithm of equation (5) and rearranging one obtains

$$H=kT\ ln\ (\nu/\dot{\gamma}) \qquad (12)$$

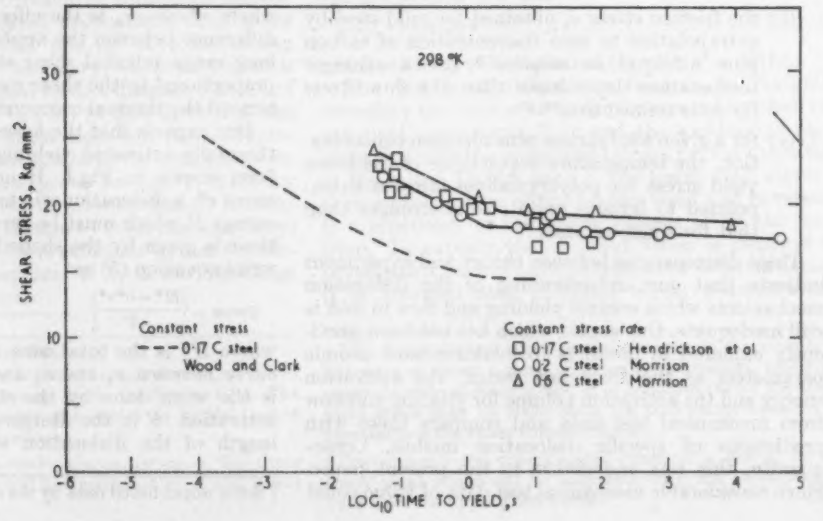
Equation (12) indicates that, when $\nu$ is a constant, $H$ is proportional to the temperature for a constant strain rate.

## EXPERIMENTAL DATA

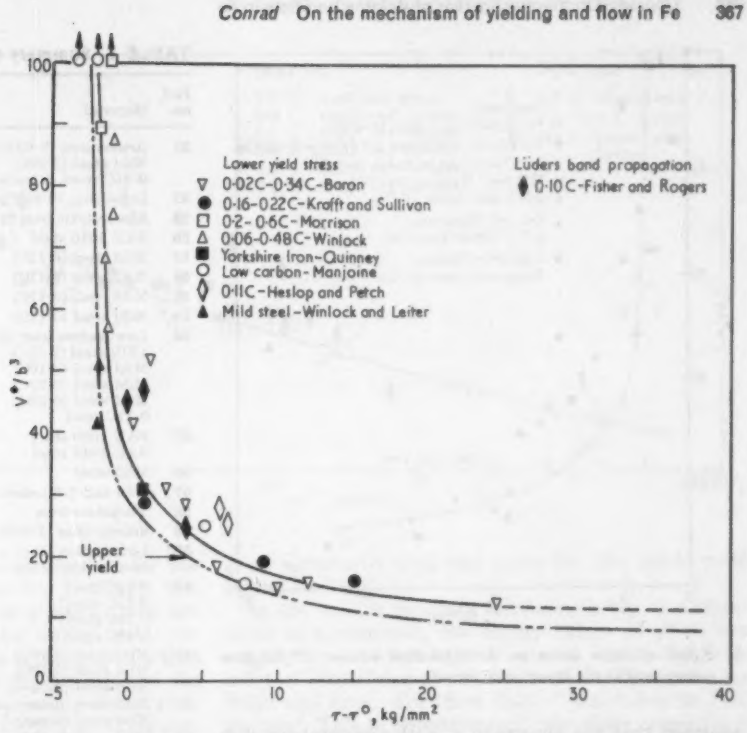
### General

The values of $H$, $v^*$, and $\nu$ were determined by

‡ If the total energy is a function of stress, then the quantity $\left\{\left(\frac{\partial \ln \dot{\gamma}/\nu}{\partial \tau^*}\right)_T kT\right\}$ is not the 'true' activation volume, but rather simply represents $-\left(\frac{\partial H}{\partial \tau^*}\right)_T$




**3** *Variation of time to yield with stress at 298°K*




**4** *Effect of shear stress on the activation volume* $v^*$ *for initial yielding in iron and steel*

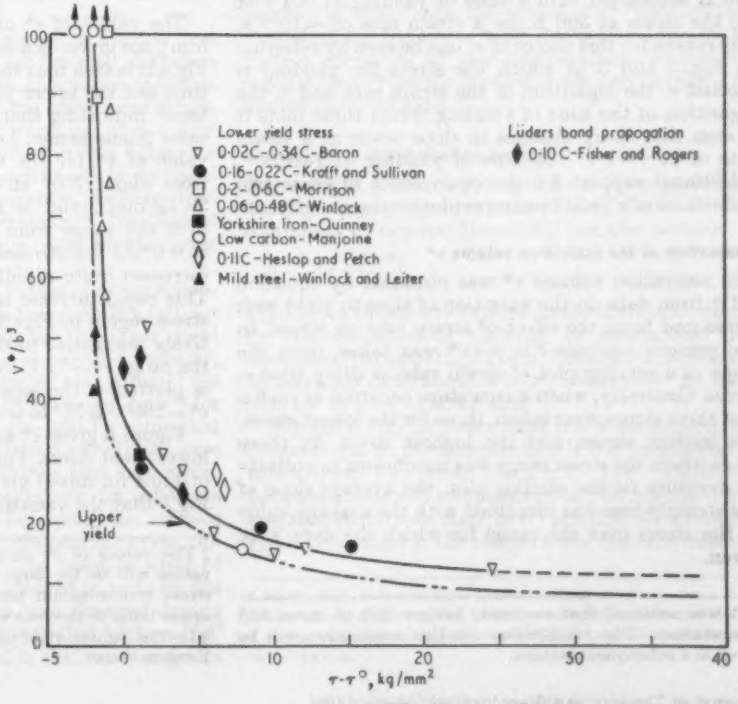
equations (6), (6*a*), (11), and (12) for the materials and testing conditions listed in Table I. To study the effect of stress on $H$ and $v^*$ comparisons between the various materials had to be made at the same value of $\tau^*$. Since $\tau_\mu$ could not be obtained directly from the available data, it was decided to eliminate the athermal component of the stress for a given material by subtracting a reference stress $\tau^\circ$ from the applied stress. For example, since the yield stress is given by

$$\tau\,(T,\dot{\gamma})=\tau^*\,(T,\dot{\gamma})+\tau_\mu \quad \ldots\ldots(13)$$

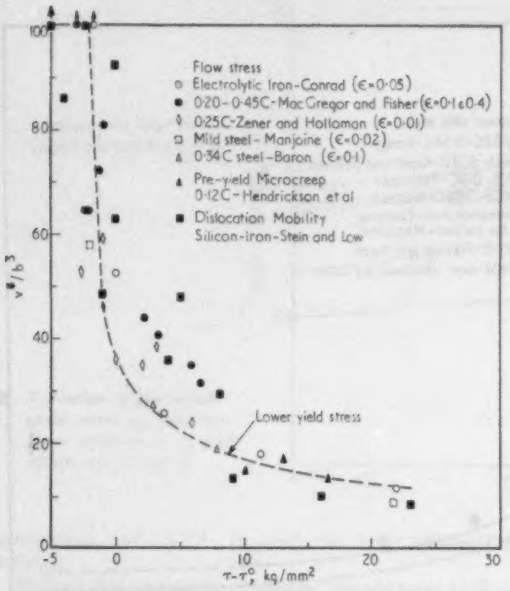
then for a constant value of $\tau_\mu$

$$\tau\,(T,\dot{\gamma})-\tau^\circ\,(T,\dot{\gamma})=\tau^*-\tau^{\circ *} \quad \ldots\ldots(14)$$

and the athermal component is eliminated. It is here




**5** *Effect of shear stress on the activation volume* $v^*$ *for the lower yield point in iron and steel*




6 *Effect of shear stress on the activation volume* $v^*$ *for flow subsequent to the lower yield stress*

assumed that the change in $\tau_\mu$ with temperature, due to the change in shear modulus with temperature, is small compared to the change in $\tau^*$ with temperature. In view of the strong temperature dependence of the yield and flow stress in iron, this assumption is justified.

The choice of $\tau^\circ$ is somewhat arbitrary. In the present analysis $\tau^\circ$ was chosen as either (a) the stress at 300°K associated with a time of yielding of ~1 s or (b) the stress at 300°K for a strain rate of $\sim 10^{-1}$ s. The reason for this choice of $\tau^\circ$ can be seen by referring to Figs.2 and 3 in which the stress for yielding is plotted $v$. the logarithm of the strain rate and $v$. the logarithm of the time of yielding. From these plots it is seen that sharp changes in slope occur at a strain rate of $10^{-1}$—1 $s^{-1}$ or time of yielding of 1–10 $s^{-1}$. Additional support for the equivalence of these two definitions of $\tau^\circ$ will become evident subsequently.

### Evaluation of the activation volume $v^*$

The activation volume $v^*$ was obtained by equation (11)† from data on the variation of time to yield with stress and from the effect of strain rate on stress. In the present analysis $\partial \ln \dot{\gamma}/\partial \tau^*$ was taken from the slope of a semilog plot of strain rate or delay time $v$. stress. Generally, when a curvature occurred in such a plot three slopes were taken, those for the lowest stress, the median stress, and the highest stress. In those cases where the stress range was insufficient to indicate a curvature on the semilog plot, the average slope of the straight line was identified with the average value of the stress over the range for which the data were given.

† It was assumed that $\nu$=const. independent of stress and temperature. The justification for this assumption will be given in a subsequent section.

**TABLE I Summary of data considered**

| Ref. no. | Material | ASTM grain size no. | Type of test |
|---|---|---|---|
| 51 | Armco iron (0·021C) | | $T$–$\dot{\epsilon}$ |
| | Mild steel (0·20C) | | |
| | 0·34C steel, quench and temper | | |
| 52 | Ingot iron (0·012C) | 4 | $S$–$\dot{\epsilon}$ |
| 25 | Electrolytic iron (0·014C) | 8 | $T$–$\dot{\epsilon}$ |
| 25 | SAE 1010 steel | 8 | $T$–$c_L$ |
| 12 | Mild steel (0·12C) | 6·7 | $T$–$\sigma$ |
| 53 | Mild steel (0·17C) | 6·5 | $T$–$P_n$ |
| 54 | Mild steel (0·17C) | 6·5 | $T$–$\sigma$ |
| 29 | Mild steel (0·11C) | 4–7 | $T$–$\dot{\epsilon}$ |
| 55 | Low carbon iron (0·01C) | 6 | $C$–$P_t$ |
| | 1010 steel (0·11C) | 7·5 | $C$–$P_t$ |
| | Mild steel (0·16C) | 8 | $C$–$P_t$ |
| | Mild steel (9·22C) | 9 | $C$–$P_t$ |
| | Mild steel (0·22C) | 8 | $C$–$P_t$ |
| | 0·31C steel | 8 | $C$–$P_t$ |
| 27 | SAE 1020 steel | | $T$–$\dot{\epsilon}$ |
| | SAE 1045 steel | | $T$–$\dot{\epsilon}$ |
| 56 | Mild steel | | $T$–$\dot{\epsilon}$ |
| 57 | 0·20 and 0·6C steel | | $T$–$\dot{\epsilon}$ |
| 58 | Yorkshire iron | | $T$–$\dot{\epsilon}$ |
| 26 | Silicon–iron (3·25Si, 0·005C) | Single crystal | $B$–$P_d$ |
| 59 | Low carbon steel | 20/in² | $T$–$\dot{\epsilon}$ |
| | Low carbon steel | 200/in² | $T$–$\dot{\epsilon}$ |
| 60 | 0·06C steel | | $T$–$\dot{\epsilon}$ |
| | 0·21C steel | | $T$–$\dot{\epsilon}$ |
| | 0·34C steel | | $T$–$\dot{\epsilon}$ |
| | 0·48C steel | | $T$–$\dot{\epsilon}$ |
| 61 | Mild steel (0·17C) | 6·5 | $T$–$P_t$ |
| | Mild steel (0·12C) | 6·7 | $T$–$P_t$ |
| | Mild steel (decarb) | 6·1 | $T$–$P_t$ |
| | Mild steel (decarb and recarb) | 6·1 | $T$–$P_t$ |
| | Mild steel (decarb + renitride) | 6·1 | $T$–$P_t$ |
| 62 | Mild steel (0·12C) | 6·7 | $T$–$P_n$ |
| 31 | 0·25C steel (tempered bainite) | | $T$–$\dot{\epsilon}$ |

$T$ = Tension; $C$ = Compression; $S$ = Torsion; $B$ = Bending

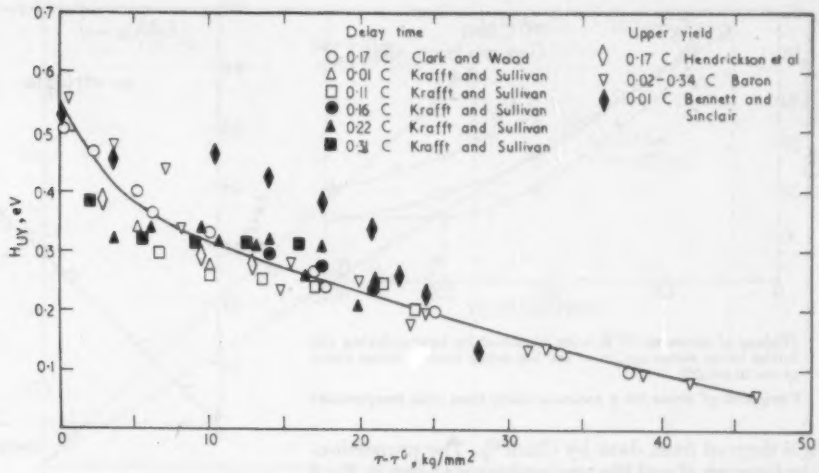
$\dot{\sigma}$ = constant stress rate; $\dot{\epsilon}$ = constant strain rate; $P_t$ = stress pulse—delay time studies; $P_n$ = stress pulse—microstrain studies; $P_d$ = stress pulse—dislocation mobility studies; $c_L$ = creep—Lüders band propagation

The values of $v^*$ obtained for yielding and flow in iron‡ are given as a function of stress in Figs.4–6.§ In Fig.4 it is seen that the various data for both the delay time and the upper yield stress fall within one scatter band, indicating that both types of test measure the same phenomenon, i.e. the initiation of yielding. The value of $v^*$ for the initiation of yielding decreases from about $30b^3$ at $\tau=\tau^\circ$ to about $8b^3$ at $\tau-\tau^\circ=$ 38 kg/mm², and is independent of carbon content over the range from wet hydrogen treated material to 0·6%C. For stresses below $\tau^\circ$ the activation volume increases quite rapidly to values in excess of $100b^3$. This rapid increase in $v^*$ is associated with the low stress region in Figs.2 and 3 where the stress is relatively insensitive to the strain rate or delay time. For the range $\tau-\tau^\circ>1$, a straight line is obtained when $v^*$ is plotted $v$. the logarithm of $\tau-\tau^\circ$ and one obtains $v^*=26b^3-5{\cdot}2b^3 \ln(\tau-\tau^\circ)$.

Figure 5 gives $v^*$ as a function of the stress for the lower yield stress. For comparison, the average curve of Fig.4 for initial yielding is included. It is seen from Fig.5 that the variation of $v^*$ with stress for the lower

‡ The values of $v^*$ obtained by using the measured stress values will be too large by a factor $q$ which represents the stress concentration factor. Hence, they will represent an upper limit to the true values.

§ In the figures $v^*/b^3$ is plotted $v$. stress, where $b$ is the Burgers vector.


Delay time
○ 0·17 C Clark and Wood
△ 0·01 C Krafft and Sullivan
□ 0·11 C Krafft and Sullivan
● 0·16 C Krafft and Sullivan
▲ 0·22 C Krafft and Sullivan
■ 0·3½ C Krafft and Sullivan
Upper yield
◇ 0·17 C Hendrickson et al
▽ 0·02–0·34 C Baron
◆ 0·01 C Bennett and Sinclair
$H_{UY}$, eV
$\tau-\tau^\circ$, kg/mm²

7 *Effect of shear stress on the activation energy for the initiation of yielding in iron and steel*

yield stress shows the same general trend as for the upper yield stress (or delay time for yielding). The values of $v^*$ for the lower yield at a given stress are about 1·2–1·3 times that for the upper yield, i.e. $v^*_{ly}/v^*_{uy}=1{\cdot}2$–$1{\cdot}3$. Of significance in this regard is that the difference between the upper yield stress and the lower yield stress at a given temperature also corresponds approximately to $\sigma_{uy}/\sigma_{ly}=1{\cdot}2$–$1{\cdot}3$.[8] This suggests that the essential difference between the upper and lower yield stresses is the difference in stress concentration $q$ existing at a Lüders band front compared with that existing at the site of the formation of the initial band, rather than the operation of different mechanisms as indicated earlier.[8] The present results on $v^*$ and those on the variation of the upper and lower yield stress with temperature[8] would thus indicate that $q_{ly}/q_{uy}=1{\cdot}2$–$1{\cdot}3$.

A further point of interest in regard to Fig.5 is that $v^*$ obtained from measurements of the rate of Lüders band propagation[25] agrees with the value obtained from the effect of strain rate on the lower yield stress.

Figure 6 gives the effect of stress on $v^*$ for flow beyond the Lüders strain. Included in this figure are values of $v^*$ obtained from measurements of pre-yield microcreep and of dislocation velocities in silicon–iron determined by an etch-pit technique.[26] The dashed curve in this figure is the average curve for the lower yield stress given in Fig.5.

It is seen from Fig.6 that the values of $v^*$ for microcreep, the flow stress, and dislocation mobility fall, for the most part, about the curve for the lower yield stress. However, in the range of $\tau-\tau^\circ=2$–8 kg/mm², two sets of data, that by MacGregor and Fisher[27] for the flow stress in steel and that by Stein and Low[26] for the dislocation mobility in silicon–iron lie somewhat above the curve for the lower yield stress. In the case of the data by MacGregor and Fisher, this may represent an effect of strain rate on structure, for the value of $\partial ln\dot{\gamma}/\partial\tau^*$ was evaluated by comparing the stresses at a constant strain on the stress–strain curves obtained at different strain rates. The possible effect of strain rate on structure was eliminated in tests by the author,[28] where the strain rate was changed during deformation, i.e. by employing so-called 'differential' tests. The values of $v^*$ obtained in this manner are in good agreement with the curve for the lower yield stress; *see* Fig.6.

In the case of the data for the mobility of dislocations in silicon–iron, the higher values of $v^*$ in the range of $\tau-\tau^\circ=2$–8 kg/mm² can be due to the difficulty of identifying $\tau^\circ$ exactly from the data given by Stein and Low. For these data $\tau^\circ$ was taken as 14·5 kg/mm². This is approximately the shear stress for a dislocation velocity of $10^{-4}$ cm/s at 298°K.

There are two additional points in regard to $v^*$ for flow worthy of mention. First, $v^*$ for the pre-yield microstrain obtained from the data by Hendrickson *et al.*[12] falls near the curve of Fig.6 only if the *total* applied stress is considered rather than $\tau-\tau^\circ$. Second, since $k^*$ of equation (1) for the lower yield stress at 194°K was found by Heslop and Petch[29] to be independent of strain rate, the values of $v^*$ obtained from their data for the lower yield stress also apply to the friction stress $\sigma_i$ at this temperature. Hence, one expects that $v^*$ for the friction stress also lies along the dashed curve of Fig.6.

### Evaluation of the activation energy $H$

The value of $H$ can be obtained from the experimental data by employing equations (6) and (6*a*)†. Further, combining equations (6) and (11) one also obtains

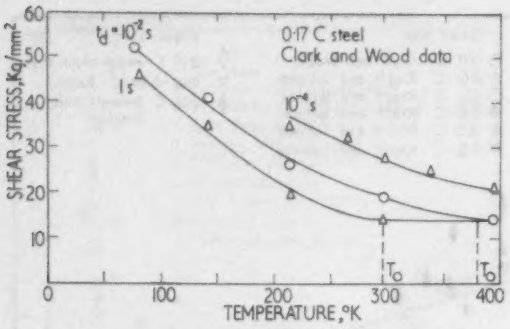
$$H=-v^*\,T\left(\frac{\partial\tau^*}{\partial T}\right)_{\dot{\gamma}} \qquad \text{.....(15)}$$

Fig.7 gives the effect of stress on the activation energy for the initiation of yielding as determined from equations (6*a*) and (15)‡. From this figure it is seen that $H$ decreases from about 0·5–0·6 eV at $\tau=\tau^\circ$ to about 0·06 eV at $\tau-\tau^\circ=46$ kg/mm².

Equation (12) indicates that if $\nu$ is a constant $H$ is proportional to the temperature if the temperature is substituted for stress in Fig.7. The relationship between stress and temperature can be obtained from constant strain rate tests, or by plotting the stress for a given delay time $v$. the temperature (*see*, for example,

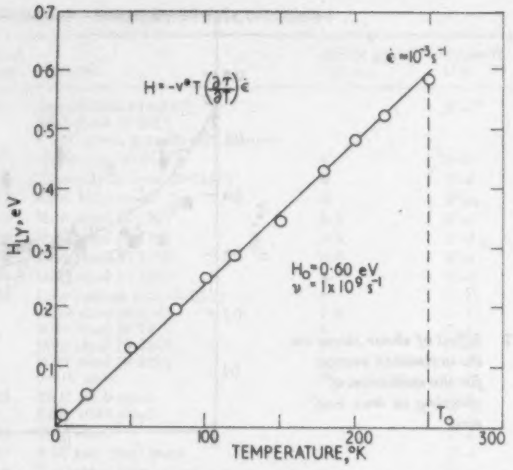
† Here, also, it is assumed that $\nu=$const.

‡ The values of $H$ derived from these equations do not include a stress concentration factor and hence can be considered as 'true' values.




(Values of stress at 78°K were obtained by extrapolating the initial lower stress region of the log delay time *v.* stress curve given in ref.30)

**8** *Variation of stress for a constant delay time with temperature*




**10** *Variation of the activation energy for the lower yield stress of iron and steel with temperature*

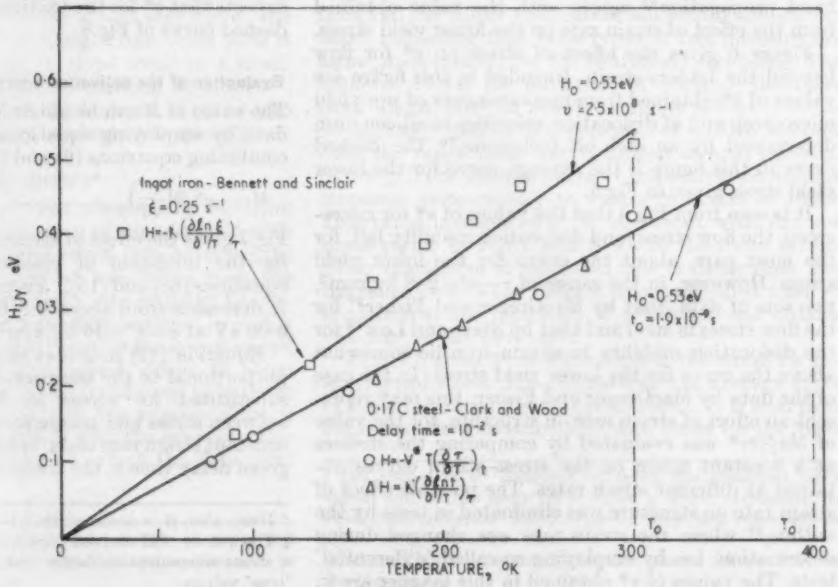
Fig.8 derived from data by Clark[30]). The proportionality between $H$ and the temperature is shown in Fig.9 for the two materials (ingot iron and mild steel) for which sufficient data were available for the evaluation. The value of $H_o$ for $T = T_o$ ($\tau = \tau^\circ$) is 0·53 eV for both materials.

A plot of $H$ *v.* temperature for the lower yield stress is given in Fig.10, where $H_o = 0{\cdot}60$ eV. The data points for this figure were derived by taking the values of $v^*$ from the average curve given in Fig.5 and the values of $\partial\tau^*/\partial T$ from the average curve for the effect of temperature on the lower yield stress of various irons and steels with a *total* carbon plus nitrogen content greater than 0·01% by weight. (Curve *A* in Fig.2 of ref.23).

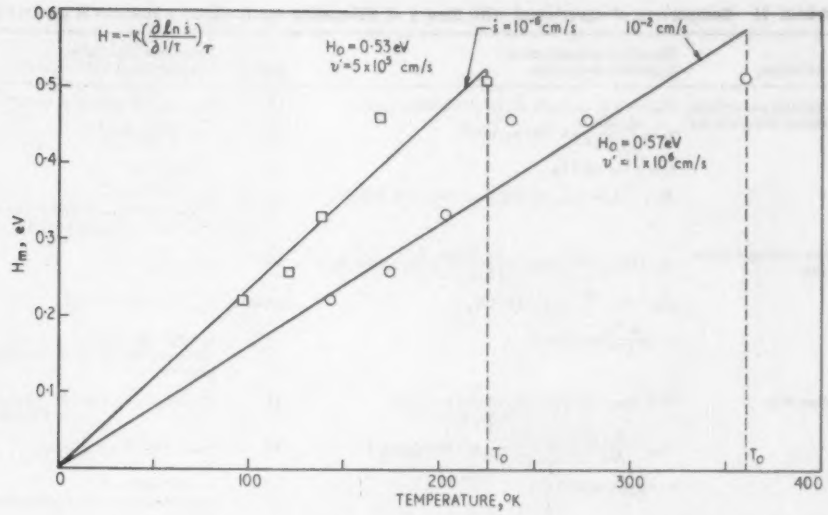
Since the temperature dependence of the friction stress $\sigma_i$ and the flow stress $\sigma_{fl}$ is practically the same as that for the lower yield stress[8] and since the values of $v^*$ are practically the same (*see* Fig.6), the variation of $H$ with temperature for the friction stress and the flow stress will be the same as that given in Fig.10 for the lower yield stress. Similarly the value of $H_o$ (~0·6 eV) will be the same for all three parameters.

Of special significance is an evaluation of $H_o$ for the mobility of dislocations in silicon–iron, for here one deals directly with the motion of free dislocations. The variation of $H$ with temperature obtained from the data given by Stein and Low[26] in their Fig.9 is presented in Fig.11 of the present paper for two dislocation velocities, namely $10^{-2}$ cm/s and $10^{-6}$ cm/s. It is noted in Fig.11 that $H_o = 0{\cdot}53$–$0{\cdot}59$ eV in agreement with the values for the upper yield, lower yield, and flow stresses of iron and steel.

Finally, it should be mentioned that the value of $H_o$ obtained in the present analysis is in agreement with that obtained by Zener and Holloman[31] (0·44–0·61 eV) for yielding and flow in iron. Also, the effect


$H_{LY}$ eV
TEMPERATURE, °K
$H_o = 0{\cdot}53$eV
$\nu = 2{\cdot}5 \times 10^8$ s$^{-1}$
Ingot iron - Bennett and Sinclair
$\dot{\epsilon} = 0{\cdot}25$ s$^{-1}$
$H = -k\left(\frac{\partial \ln \dot{\epsilon}}{\partial 1/T}\right)_\tau$
$H_o = 0{\cdot}53$eV
$t_o = 1{\cdot}9 \times 10^{-6}$ s
0·17C steel - Clark and Wood
Delay time = $10^{-2}$ s
$H = -V^* T\left(\frac{\partial \tau}{\partial T}\right)_\dot{\epsilon}$
$\Delta H = k\left(\frac{\partial \ln t}{\partial 1/T}\right)_\tau$
$T_o$
$T_o$

**9** *Variation of the activation energy for the initiation of yielding of iron and steel with temperature*




**11** *Variation of the activation energy for dislocation motion with temperature in* 3·25%Si–Fe

of stress on the activation energy $H$ (for example, as given in Fig.7) could be expressed in the form

$$H=H_0-c\ ln\ (\tau/\tau^\circ) \quad \ldots\ldots(16)$$

indicating that the activation energy decreases approximately with the logarithm of the stress, in agreement with the findings of Yokobori[33] and Campbell.[34, 35]

The value of $c$ of equation (16) increased with increase in $\tau^\circ$. An approximation to this effect of $\tau^\circ$ was

$$c=1{\cdot}5(\tau^\circ)^{\frac{1}{2}} \quad \ldots\ldots(17)$$

when $c$ is expressed in electron volts and $\tau^\circ$ in kg/mm$^2$. For mild steel ($\tau^\circ\approx14$ kg/mm$^2$) one obtains $c\approx0{\cdot}3$ eV.

#### Evaluation of the frequency factor $\nu$

One can obtain $\nu$ of equation (5) from the slopes of the plots of $H$ *v.* temperature, such as those of Figs.9 and 10. These yield $\nu=10^8$–$10^9$ s$^{-1}$ for the upper and lower yield stress when the shear strain rate $\dot{\gamma}$ is taken to be 3/2 the tensile strain rate $\dot{\epsilon}$. Since the flow stress beyond yielding exhibited the same $v^*$, $H$, and temperature dependence as the lower yield stress, $\nu$ for flow is also $\approx10^8$–$10^9$ s$^{-1}$. Further, writing for the delay time $t_d$:

$$t_d=t_0\ e^{H/kT} \quad \ldots\ldots(18)$$

one obtains from Fig.9, $t_0=1{\cdot}9\times10^{-9}$ s for the initial yielding of a mild steel, indicating that $t_0\approx1/\nu$. Finally, writing for the dislocation velocity $\dot{s}$ studied by Stein and Low[26]

$$\dot{s}=\nu'\ e^{-H/kT} \quad \ldots\ldots(19)$$

one obtains from Fig.11, $\nu'=10^5$–$10^6$ cm/s$^{-1}$.

From a knowledge of $\nu'$ one can obtain an estimate of the dislocation density $\rho$ involved in yielding and flow for

$$v=\rho\ b\ \nu' \quad \ldots\ldots(20)$$

Using the above values of $\nu$ and $\nu'$ one obtains $\rho\approx10^{10}$ cm$^{-2}$, which is compatible with the dislocation density obtained by Harper[36] from internal friction studies on cold-worked iron. Further, from the data on pre-yielding microcreep[12] one obtains $\nu=1$ s$^{-1}$. Using this value in equation (20) gives $\rho=10^2$ cm$^{-2}$, indicating that only a small fraction of the initial dislocation density (estimated to be $\approx10^8$ cm$^{-2}$) is involved in microcreep.

Several factors suggest that $\nu$ (or $t_0$) is relatively independent of stress and temperature.† First, the fact that the derived values of $H$ are proportional to the temperature strongly suggests that $\nu\approx$const. If this is so, then either $\nu$ is independent of stress and temperature or the combined effect of stress and temperature is such as to maintain $\nu$ constant. In the latter case, if $\nu$ is independent of either stress or temperature, then it must be independent of both. The fact that, in general, one obtains a straight line when the logarithm of the strain rate at a constant stress is plotted *v.* the reciprocal of the temperature suggests that $\nu$ is relatively independent of temperature, and hence of stress as well. Also, the fact that the activation volume obtained from equation (11) was primarily a function of stress alone over a wide temperature range supports the assumption that $\nu$ is relatively independent of stress and temperature.

## DISCUSSION

In the preceding section it was found that at low temperatures the initiation of yielding (delay time for yielding and the upper yield stress), the propagation of yielding (Lüders band propagation and the lower yield stress), and subsequent flow (dislocation mobility and the flow stress beyond the Lüders strain) all exhibit essentially the same values of the activation volume $v^*$ and the activation energy $H$ as a function of stress. Also, wherever comparison was possible, there was good agreement in the values of the frequency factor $\nu$. This suggests that either these phenomena are controlled by the same dislocation mechanism or by different mechanisms which are characterized by nearly the same values of $v$, $v^*$, and $H$. In the present

† Unless the effects of stress and temperature on $\nu$ are very strong (for example, an exponential or power effect), they will be overshadowed by the role stress and temperature play in the Boltzmann exponential.

**TABLE II Comparison of experiment with theory of dislocation mechanisms which could control yielding and flow in iron**

| Mechanism | Theoretical estimates: equation and value | Ref. | Experimental data: equation and value | Ref. |
|---|---|---|---|---|
| Breaking away from Cottrell atmosphere | $H_i = 0{\cdot}9\,(1-\tau/\tau_o)^2$; $H_i\,(\tau/\tau_o = 0{\cdot}25) = 0{\cdot}38$ eV | 17 | $H_i\,(\tau/\tau_o = 0{\cdot}25) = 0{\cdot}5$–$0{\cdot}6$ eV | |
| | $\tau_o = \dfrac{H_i\,(\tau=0)}{4{\cdot}5\,b^3} \approx 200$ kg/mm$^2$ | 17 | $\tau_o = 55$ kg/mm$^2$ | |
| | $t_o \approx \dfrac{10^3}{\nu_d} = 10^{-11}$ s | 17 | $t_o = 10^{-8}$–$10^{-9}$ s | |
| | $H_i = -\alpha \ln \tau/\tau_o$; $H_i\,(\tau/\tau_o = 0{\cdot}25) = 0{\cdot}4$–$0{\cdot}6$ eV | 15, 33 | $H_i = H_o - c \ln \tau/\tau^\circ$<br>Upper and lower yield points are associated with the presence of C and N | 1–3 |
| Overcoming Peierls stress | $\tau_p\,(110) = \dfrac{2\mu}{1-\nu^*}\exp.-\left[\dfrac{2\pi a}{b\,(1-\nu^*)}\right] = 2\times10^{-3}\mu$ | 38 | $\tau_p = 5\times10^{-2}\,\mu$ | |
| | $E_m - E_o = \dfrac{b^2\tau_p}{\pi} \approx 1\times10^{-3}\,E_m$ | 39, 40 | $E_m - E_o = 3\times10^{-3}\,E_m$ | 12, 13 |
| | $\nu = \rho\dfrac{\frac{1}{2}b\,\nu_d}{L^{*2}} \approx 10^8$ s$^{-1}$ | | $\nu = 10^8$–$10^9$ sec$^{-1}$<br>Dislocations in Si–Fe lie along close-packed directions | 44 |
| Cross-slip | $H = H_Q - c \ln \tau/\tau^\circ$; $H_Q$ (Al) $\approx 1$ eV, $c$ (Al) $\approx 0{\cdot}35$ eV | 41 | $H = H_Q - c \ln \tau/\tau^\circ$; $H_Q$ (Fe) $= 0{\cdot}5$–$0{\cdot}6$ eV, $c$ (Fe) $= 0{\cdot}2$–$0{\cdot}35$ eV | |
| | $\gamma_{Al} = \left\{\dfrac{H_Q\,(\mathrm{Cu})\,\mu\,(\mathrm{Al})}{H_Q\,(\mathrm{Al})\,\mu\,(\mathrm{Cu})}\right\}\gamma_{Cu} \approx 140$ ergs/cm$^2$ | 42 | $\gamma_{Fe} = 150$–$250$ ergs/cm$^2$ | |
| | $\nu = \dfrac{b^2}{L^{*2}}\nu_d \approx 10^{10}$ s$^{-1}$ | | $\nu = 10^8$–$10^9$ s$^{-1}$<br>Copious cross-slip occurs during deformation of iron | |
| Motion of jogs in screw dislocations | $H = H_f^v - L^*$; $b\,d\,\tau^*$; $H_f^v \approx 1{\cdot}5$ eV | 43 | $H_f^v = 0{\cdot}5$–$0{\cdot}6$ eV | |
| | $L^*_j = 50\,b$ | 19 | $L^*_j = 30\,b$ | |
| | $\nu = \rho\dfrac{b^3\nu_d}{L^*_j} \approx 10^8$ s$^{-1}$ | | $\nu = 10^8$–$10^9$ s$^{-1}$ | |

$H_i$ = Energy for unlocking
$H_K$ = Kink energy
$H_Q$ = Energy for cross-slip
$H_f^v$ = Energy to form a vacancy
$E_m$ = Maximum dislocation line energy
$E_o$ = Minimum dislocation line energy
$\mu$ = Shear modulus
$\nu^*$ = Poissons ratio
$\nu_d$ = Debye frequency
$b$ = Burgers vector
$a$ = Spacing between slip planes
$\nu$ = Frequency factor
$\gamma$ = Stacking fault energy
$\rho$ = Dislocation density
$L^*$ = Length of dislocation segment
$L^*_j$ = Distance between jogs
$d$ = Activation distance
$\tau$ = Applied shear stress
$\tau^*$ = Effective shear stress
$\tau_o$ = Applied shear stress at 0°K
$\tau_p$ = Peierls shear stress at 0°K
$\tau^\delta$ = Yield stress at 300°K for a strain rate of $10^{-1}$ s$^{-1}$
$\alpha$, $c$, $t_o$ = Constants

section a comparison will be made between the experimental values of these parameters and those predicted by specific dislocation models to see if the controlling mechanism (or mechanisms) can be identified.

Dislocation mechanisms which might control yielding or flow in iron at low temperatures are:

(i) breaking away from a Cottrell atmosphere
(ii) overcoming the Peierls stress
(iii) intersection of dislocations ('cutting the forest')
(iv) cross-slip
(v) production of vacancies or interstitials at jogs in dislocations with a screw component.

Of these, the intersection of dislocations can be immediately eliminated for two reasons: (*a*) the experimental activation volume (10–30$b^3$) is several orders of magnitude smaller than one expects for this mechanism[37] and (b) the measured activation volume does not decrease with strain[8, 28] as is expected for a metal such as iron where slip occurs on several planes. These limitations do not apply to the four remaining mechanisms and a more detailed comparison between experiment and theory was made, which is summarized in Table II. From this table it is seen that there is some agreement between theory and experiment for all four mechanisms, making it difficult to identify the one which is controlling.

Initially, let us consider the movement of 'free' dislocations as given by the mobility determined by etch pits or by the flow stress beyond the Lüders strain. Here we can eliminate the breaking away from a Cottrell atmosphere as the controlling mechanism, leaving overcoming the Peierls stress, cross-slip, and the movement of jogs in screw dislocations as possible mechanisms. For each of these mechanisms the estimated activation volume†‡ (~10–50$b^3$) and frequency factor ($10^8$–$10^{10}$ s$^{-1}$) are in accord with the experimental values. Referring to Table II, further comparison between theory and experiment indicates that for the *motion of jogs* in screw dislocations the activation energy is only about $\frac{1}{3}$ that expected for the formation of vacancies in iron on the basis that the energy to form a vacancy is about $\frac{1}{3}$ of the energy for self-diffusion (~3 eV). In the case of the *Peierls mechanism* the experimental Peierls stress and energy are about three times that estimated theoretically. However, in view of the approximations involved in calculating the Peierls stress, this is not a serious disagreement. Since no theoretical calculations have been

† For the movement of jogs in screw dislocations Schoeck[19] has calculated the density of jogs which will be frozen-in as a result of cooling from above one-half the melting temperature in °K. This gives a spacing between jogs, $L^*_j$, of ~50$b$ and hence an activation volume $v^*_o$ of ~50$b^3$. Likewise, Seeger's treatment[39] of the Peierls mechanism and Schoeck and Seeger's treatment[41] of cross-slip suggest that the length $L^*$ of dislocation segment involved in the thermal activation is ~10–50$b$ and hence $v^*_o \approx 10$–$50b^3$.

‡ The total energy may vary with stress for the Peierls and cross-slip mechanisms; hence $v^*$, as given by equation (11), may not represent the 'true' activation volume.

made for *cross-slip* in iron, the present experimental values are compared with calculations on aluminium, which also exhibits considerable cross-slip. From Table II it is seen that the experimental activation energy, its stress dependence, and the derived stacking-fault energy for iron are in agreement with those for cross-slip.

The above comparisons do not permit a positive choice between the three mechanisms. However, Stein and Low's observation[26] that the yield stress in silicon–iron exhibits the same temperature dependence as the mobility of edge dislocations, which cannot cross-slip, favours the *Peierls* or *dragging of jogs*† over the *cross-slip* mechanism.

For further comparison it is of interest to determine from the data of Stein and Low[26] the value of the average distance $s$ an edge dislocation segment $L$‡ moves per successful thermal fluctuation. This can be obtained from the value of the frequency factor $v'$ given in Fig.11. For the *Peierls* mechanism

$$s=\frac{L^{*2}\nu'}{Lbv_d}\approx b \qquad (21)$$

while for the *dragging of a jog*

$$s=\frac{L^{*}\nu'}{bv_d}\approx 100b \qquad (22)$$

where $L$ is the average length of an edge dislocation§ ($\sim 10^{-4}$ cm), $b$ is the Burgers vector, $L^*$ is the length of dislocation segment involved in thermal activation ($\sim 30b$), and $v_d$ is the Debye frequency ($10^{13}$ s$^{-1}$). The values of $s$ obtained by equations (21) and (22) are in accord with the respective mechanisms and hence a separation cannot be made on this basis.

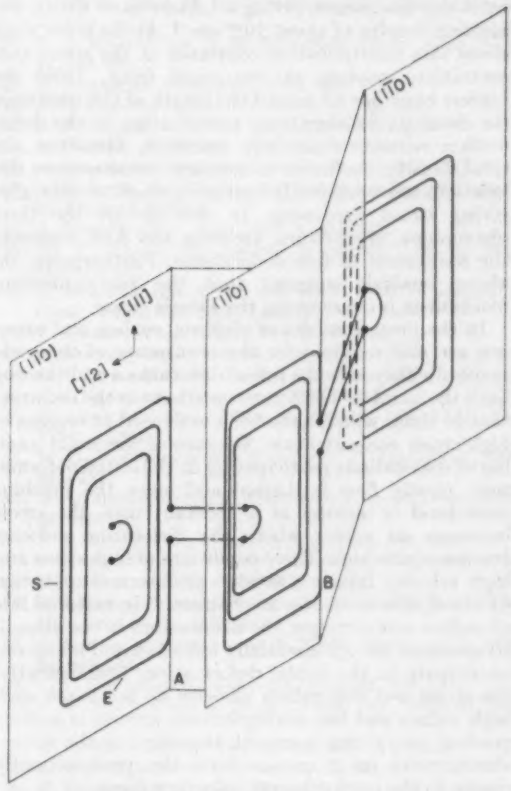
However, two additional facts favour the *Peierls* mechanism over *dragging of jogs*: (*a*) the dislocations in silicon–iron lie along close-packed directions,[44] suggesting a high Peierls stress, and (*b*) if the dragging of jogs is controlling, one would expect a change in $v^*$ with strain, which is not observed. These factors, plus the fact that the observed activation energy of 0·5–0·6 eV is somewhat low for the production of vacancies, suggest that the controlling mechanism for the motion of free dislocations is the overcoming of the *Peierls* stress hills. Further, since the values of $\nu$, $H$, and $v^*$ for the lattice friction stress are the same as for the flow stress, one can conclude that overcoming the Peierls stress is also the controlling mechanism here.

Since $k^*$ of equation (1) is independent of temperature and since its value is the same for both yielding and flow beyond the Lüders strain, Conrad and Schoeck[8] have suggested that perhaps it represents a stress other than the Cottrell locking stress. If this is the case, then the upper and lower yield stress must represent the sudden generation of a large number of dislocations by some mechanism other than the breaking away from a Cottrell atmosphere. One mechanism which could produce large numbers of dislocations and would be in accord with observations on silicon–iron[44] is the double cross-slip mechanism originally proposed by Koehler[45] and Orowan[46] and discussed by Low and Guard[44] and Johnston and Gilman[47] (*see* Fig.12). The operation of this double cross-slip could be controlled by the mobility of the edge component in two ways:

(i) from a purely geometric standpoint, the farther the edge component moves, the greater is the length of screw component formed, and hence the greater is the probability that cross-slip will occur

(ii) Johnston and Gilman[47, 48] have shown in LiF that new dislocations are created out of the wake of a moving dislocation and that the number of new dislocations is proportional to the distance travelled by the original dislocation loop.

The stress–strain behaviour of iron and steel may thus represent the following: during the initial loading of the specimen below the upper yield stress, some dislocations are torn from their Cottrell atmosphere at regions of stress concentrations, such as inclusions or precipitates. As the stress is increased their mobility increases and some multiplication occurs by the double cross-slip mechanism. This gives the pre-yield microstrain. At a critical stress, first reached near the specimen grips, and representing the upper yield stress, sudden profuse multiplication occurs by the double




(110)—Principal slip plane
A, B—Cross-slip planes
S—Screw component
E—Edge component

**12** *Multiplication of dislocations by the double cross-slip mechanism of Koehler and Orowan, after Low and Guard*[44]

‡ Vacancies can be produced at jogs in mixed dislocations of predominantly edge character.

§ The value of $L$ was taken as $\frac{1}{10}$ of the distance moved by the edge dislocation, for Low and Guard[44] found that the edge components in silicon–iron moved on the average 20 times farther than the screw components.

cross-slip mechanism giving a Lüders band with a dislocation density of about $10^{10}$ cm$^{-2}$. At the lower yield stress this multiplication continues at the stress concentration existing at the band front. Once the Lüders band has traversed the length of the specimen, the density of dislocations contributing to the deformation remains essentially constant. However, the total density continues to increase because some dislocations are continually becoming stuck or entangled giving strain hardening. In this picture the three phenomena, microstrain, yielding, and flow, represent the movement of free dislocations. Furthermore, the above analysis suggests that the rate-controlling mechanism is overcoming the Peierls stress.

In the present model of yielding, carbon and nitrogen are still required for the occurrence of the yield point, for they lock the initial dislocations and thereby limit the number which can contribute to the deformation to those which have been activated at regions of high stress concentration. Because of the small number of dislocations participating in the initial deformation, plastic flow is limited and since the machine cross-head is moving at a constant rate, the stress increases to values where the dislocation velocity becomes quite high. These conditions of high stress and high velocity favour a sudden profuse multiplication by the double cross-slip mechanism.[48] In material free of carbon and nitrogen, the dislocations in the annealed specimen are all essentially unlocked and many can participate in the initial deformation. Consequently, the stress and dislocation velocity do not reach such high values and the multiplication process is a more gradual one, giving a smooth transition in the stress–strain curve as it passes from the predominantly elastic to the predominantly plastic regions.

Strain-ageing can then be explained as follows: carbon and nitrogen diffuse to the free dislocations produced during the deformation and lock them by forming a Cottrell atmosphere. Upon restressing, the situation will be similar to that in the initial annealed material, i.e. only a limited number of dislocations will be unlocked or activated at regions of high stress concentration, and a yield point will again occur owing to sudden profuse multiplication by the double cross-slip mechanism.

At present, there are insufficient data on single crystals and high purity polycrystals of iron to ascertain the reason for the weaker temperature dependence of the yield stress of these materials compared with impure polycrystalline specimens. It may be that the frequency factor is larger (for example, the number of dislocations involved in the deformation or the total strain associated with a thermal fluctuation† is larger) for the materials which show the weaker temperature dependence of the yield stress. If this were the case, the value of the stress at 0°K should be the same for both classes of materials and a sudden rise in the yield stress should occur at very low temperatures in those materials which exhibit the weaker temperature dependence. Some evidence for such a sudden rise is indicated by the yield stress data of Allen, Hopkins, and McLennan[49] on iron single crystals. However, this rise was not observed by Smith and Rutherford[22] for zone refined polycrystals tested as low as 4°K. It may be that in this latter case the steep rise was prevented by the occurrence of twinning and the erratic deformation which was always observed at these very low temperatures.

The data of Figs.2 and 3 and the present analysis suggest that a different mechanism is controlling in the range where $\tau < \tau^\circ$ as compared with that where $\tau > \tau^\circ$. Since the stress is relatively independent of temperature in this region, Schoeck and Seeger[50] have proposed that the governing mechanism is the escape of dislocations from dilute atmospheres formed by a Snoek-type ordering of interstitials in the stress fields of the dislocations. Since both the strength and radius of such an atmosphere are inversely proportional to the temperature, the yield stress, which is given by the ratio of the two, is independent of temperature. Support for this mechanism is provided in the present analysis by the large values of the activation energy and activation volume when $\tau < \tau^\circ$; for example *see* Figs.4 and 7.

## SUMMARY AND CONCLUSIONS

The values of the frequency factor $\nu$, the activation energy $H$, and the activation volume $v^*$ were determined for low temperature yielding and flow of iron from data available in the literature, and an attempt was made to evaluate the controlling mechanism by comparing the experimental results with theoretical predictions. The following is a summary of the results of this work:

1. The data for materials with different carbon plus nitrogen contents and thermal histories were correlated by considering an effective stress given by the difference between the applied stress $\tau$ and a reference stress $\tau^\circ$ defined by the stress at 300°K and a strain rate of $10^{-1}$ s$^{-1}$ (or a delay time for yielding of 1 s).
2. Within the scatter of the experimental data, the values of the activation energy $H$, the activation volume $v^*$, and the frequency factor $\nu$ were the same for yielding and flow, suggesting that either the same dislocation mechanism is controlling in all cases or that different mechanisms exhibit about the same values of these parameters. The values of $H$, $v^*$, and $\nu$ for $\tau = \tau^\circ$ were: $H = 0{\cdot}5$–$0{\cdot}6$ eV; $v^* = 25$–$30b^3$, $\nu = 10^8$–$10^9$ s$^{-1}$.
3. The dislocation mechanism for which there was closest agreement between theoretical calculations and experimental data was overcoming the Peierls stress hills. However, owing to the inexactness of the theories and the incompleteness of the experimental data, one cannot rule out the possibility that another mechanism may be controlling.
4. It is suggested that the upper and lower yield points in iron may represent the sudden generation of a large number of dislocations by the double cross-slip mechanism of Koehler and Orowan.
5. Additional investigations on the effect of strain rate and temperature on yielding and flow in single crystals and high purity polycrystals are needed to ascertain the reason for the weaker temperature dependence of the yield stress of

† The total strain will include that due to the cross-slip of the screw components as well as that due to the movement of the edge components.

these materials compared with that for polycrystalline specimens with carbon plus nitrogen contents greater than 0·01%.

## REFERENCES


1. C. A. Edwards *et al.*: *JISI*, 1940, **142**, 199–236.
2. J. S. Snoek: *Physica*, 1941, **8**, 734.
3. J. R. Low and M. Gensamer: *Trans. AIME*, 1944, **158**, 207–249.
4. E. O. Hall: *Proc. Phys. Soc.*, 1951, **B64**, 747–753.
5. N. J. Petch: *JISI*, 1953, **174**, 25–28.
6. A. Cracknell and N. J. Petch: *Acta Met.*, 1955, **3**, 186.
7. N. J. Petch: *Phil. Mag.*, 1956, **1**, 186–190.
8. H. Conrad and G. Schoeck: *Acta Met.*, 1960, **8**, 791–796.
9. A. H. Cottrell: Report on the strength of solids, 30; 1948, London, Phys. Soc.
10. A. H. Cottrell: *Trans. AIME*, 1958, **212**, 192–203.
11. N. J. Petch: 'Progress in Metal Physics', 1; **5**, 1954, London, Pergamon Press.
12. J. A. Hendrickson *et al.*: *Acta Met.*, 1956, **4**, 593–601.
13. E. T. Wessel: *Trans. AIME*, 1957, **209**, 930–935.
14. W. S. Owen *et al.*: *Trans. ASM*, 1958, **50**, 517–540.
15. A. H. Cottrell and B. A. Bilby: *Proc. Phys. Soc.*, 1949, **62A**, 49–62.
16. J. C. Fisher: *Trans. ASM*, 1955, **47**, 451–462.
17. A. H. Cottrell: Conf. on high rates of strain, 448; 1957, London, Inst. Mech. Eng.
18. J. Heslop and N. J. Petch: *Phil. Mag.*, 1956, **1**, 866–872.
19. G. Schoeck: private communication.
20. N. J. Petch: *Phil. Mag.*, 1958, **3**, 1089–1097.
21. F. de Kazinczy *et al.*: Swampscott Conf. on Fracture, 1959, Wiley.
22. R. L. Smith and J. L. Rutherford: *Trans. AIME*, 1957, **209**, 857–864.
23. H. Conrad: *Phil. Mag.*, 1960, **5**, 745.
24. H. Conrad and H. Wiedersich: *Acta Met.*, 1960, **8**, 128–130.
25. J. C. Fisher and H. C. Rogers: *Acta Met.*, 1956, **4**, 180–185.
26. D. F. Stein and J. R. Low: *J. Appl. Phys.*, 1960, **31**, 362.
27. C. W. MacGregor and J. C. Fisher: *J. Appl. Mech.*, 1945, Dec., A217; C. W. MacGregor and J. C. Fisher: *Trans. ASME*, 1946, **68**, A11.
28. H. Conrad: unpublished data.
29. J. Heslop and N. J. Petch: *Phil. Mag.*, 1958, **3**, 1128–1136.
30. D. S. Clark: *Trans. ASM*, 1954, **46**, 34–62.
31. C. Zener and J. H. Holloman: *J. Appl. Phys.*, 1944, **15**, 22–32.
32. J. M. Krafft and A. M. Sullivan: *Trans. ASM*, 1959, **51**, 643–665.
33. T. Yokobori: *Phys. Rev.*, 1952, **88**, 1423.
34. J. D. Campbell: *Acta Met.*, 1953, **1**, 706–710.
35. J. D. Campbell: *Trans. ASM*, 1959, **51**, 659–665.
36. S. Harper: *Phys. Rev.*, 1951, **83**, 709.
37. A. Seeger: *Z. Naturforsch.*, 1954, **9a**, 758, 800, 856.
38. A. H. Cottrell: 'Dislocations and plastic flow in crystals', 62–66; 1953, Oxford.
39. A. Seeger: *Phil. Mag.*, 1956, **1**, 651–662.
40. W. T. Read: 'Dislocations in crystals', 46–54; 1953, McGraw Hill.
41. G. Schoeck and A. Seeger: Rept. Conf. of Defects in Cryst. Solids; 340, 1958, London, Phys. Soc.
42. P. Haasen: *Phil. Mag.*, 1958, **3**, 384–418.
43. A. Seeger: *ibid.*, 1955, **46**, 1194–1217.
44. J. R. Low and R. W. Guard: *Acta Met.*, 1959, **7**, 171–179.
45. J. S. Koehler: *Phys. Rev.*, 1952, **86**, 52.
46. E. Orowan: 'Dislocations in metals', 103; 1954, New York, AIME.
47. W. G. Johnston and J. J. Gilman: *J. Appl. Phys.*, 1960, **31**, 632.
48. W. G. Johnston and J. J. Gilman: *J. Appl. Phys.*, 1959, **30**, 129–144.
49. N. P. Allen *et al.*: *Proc. Roy. Soc.*, 1956, **234**, 221.
50. G. Schoeck and A. Seeger: *Acta Met.*, 1959, **7**, 469–477.
51. H. G. Baron: *JISI*, 1956, **182**, 354–365.
52. P. E. Bennett and G. M. Sinclair: *T & AM Rept.*, (157), Dec., 1959, Univ. of Illinois.
53. J. A. Hendrickson and D. S. Wood: *Trans. ASM*, 1958, **50**, 498–516.
54. J. A. Hendrickson *et al.*: *ibid.*, 1959, **51**, 629–642.
55. J. M. Krafft and A. M. Sullivan: *ibid.*, 1959, **51**, 643–665.
56. M. J. Manjoine: *J. Appl. Mech.*, 1944, **11**, A211.
57. J. L. M. Morrison: *Engineer*, 1934, **158**, 183–185.
58. H. Quinney: *ibid.*, 1936, **161**, 669–677.
59. J. Winlock and R. Leiter: *Trans. ASM*, 1937, **25**, 163.
60. J. Winlock: *Trans. AIME*, 1953, **197**, 797.
61. D. S. Clark and D. S. Wood: *Proc. ASTM*, 1949, **49**, 717; D. S. Wood and D. S. Clark: *Trans. ASM*, 1951, **43**, 571–586; D. S. Wood and D. S. Clark: *ibid.*, 1952, **44**, 726–745 D. S. Clark: *ibid.*, 1954, **46**, 34.
62. T. Vreeland *et al.*: *Acta Met.*, 1953, **1**, 414–421.



# STAL *in English*

Number 5 (May) of the 1961 series of the cover-to-cover translation of the Russian journal *Stal'* will shortly be published the principal contents are given below. Full details of subscriptions to *Stal in English* are available from the Secretary of The Iron and Steel Institute.

Effect of magnesia on the desulphurizing capacity of blast-furnace slags

Physico-chemical properties of titanium–magnesia slags with a high alumina content

Production of low-alloy converter rail steel

Improvement in mould design in continuous casting plants

Smelting of ferrosilicon in a closed electric furnace

Production of thin-walled seamless tubes in England

Non-metallic phosphorus inclusions in steel

Effect of carbon on the magnetic properties of transformer steel

Reducing rejects in telegraph-wire rod

Experimental testing of standards for twisting mass-produced steel wire ropes

Jointless crane rails in a combine shop

Ground-type stripping machine with floating shaft

# The effects of temper rolling and strain ageing on the formability of low-carbon steel

*D. V. Wilson, R. D. Butler, and B. B. Moreton*

**SYNOPSIS**

*The influence of temper rolling and strain ageing on the forming behaviour of low-carbon rimming steel sheets has been studied in uniaxial tension, biaxial stretch-forming, and deep drawing tests. Results show that the effects of the metallurgical variables on performance depend on conditions imposed by the particular tests. 1·2% rolling has little effect on uniaxial tensile elongation but reduces stretch-formability and deep drawability. Strain ageing after 1·2% temper rolling reduces performance in stretching operations but deep drawability is unaffected. 5% temper rolling causes more severe reductions in stretching performance, both directly and as a result of subsequent ageing. Strain ageing after rolling 5% reduction also reduces deep drawing performance in an operation involving a large stretch-forming component of deformation, but it has little effect if drawing is carried out with a punch of small profile radius. In general, speed effects observed in the range of drawing speeds 1 to 100 ft/min are not greatly altered by temper rolling or by strain ageing.*

*Qualitative explanations of the results can be given in terms of the observed changes in work hardening behaviour if the ranges of strain hardening relevant to failure in the different operations are considered. However, prediction of deep drawing capacities from simple mechanical tests presents a special difficulty, because drawing performance is sensitive to process and material variables which lead to relative changes in behaviour within the stretch-formed and drawing zones of the cup, but it is insensitive to general changes in plastic properties. Thus the results support the use of simulative tests for comparisons of deep drawing performances.* 1955

## INTRODUCTION

THE PROPERTIES REQUIRED in a metal, for satisfactory performance in drawing and pressing operations, depend on details of the modes of deformation and the working conditions.[1,2] Because rigorous analysis, in terms of basic stress–strain relationships, is generally intractable,[2] much attention has been given to the possibility of basing predictions of forming behaviour on the results of practical simulative tests.[1,3,4] The most reliable simulative test would be to press-form precisely the same shape as the component which is to be produced, full size or possibly as a scale model, but, generally, the information to be gained in this way is too limited in relation to its cost. However, even in the formation of complex pressings, it is generally possible to recognize that certain basic modes of deformation are involved. Thus a promising approach to the problem of testing formability is to measure limitations on the performance of the material in a small number of standardized technological tests which are designed to represent distinct basic modes of deformation, such as bending, uniaxial stretching, biaxial stretch-forming, and cylindrical deep drawing.[2,5,6] Predictions of the effects of metallurgical variables on performance in practical presswork must then be based on a judgement as to which of the possible limitations on performance shown by the tests will be important in the particular operation. Obviously much remains to be done in checking predictions against press-shop performance and in refining the bases of judgment.

At present there are rather few studies available on the effects of specific metallurgical changes on performance in the different types of technological test. This paper reports such a study of the effects of temper rolling and strain ageing on the forming properties of low-carbon rimming steel sheet. The tests used were those most likely to be of value in relation to drawing and pressing of the relatively thin sheets commonly used in large-scale production: namely, the uniaxial tensile test, biaxial stretch-forming tests, and deep-drawing tests. The effects of forming speed have been examined in the case of the drawing and large stretch-forming tests. This variable, potentially important in the case of a material sensitive to strain rate, has been neglected in earlier investigations.

Recent work suggests that strain ageing may provide an important example of a metallurgical change which affects formability in different operations in distinctly different ways. Swift cup drawing tests, made on commercially temper rolled sheets, have shown little change in deep drawing properties as a result of ageing[7,8]; yet similar materials commonly show a decrease in formability in uniaxial tension, Olsen, and Erichsen tests; also strain ageing is a recognized source of failure in the manufacture of pressings which involve a stretch-forming component of deformation.[7] There is little published information on the effects of temper rolling itself on formability, or on the way in which the effects of subsequent strain ageing are altered by variations in temper rolling practice.

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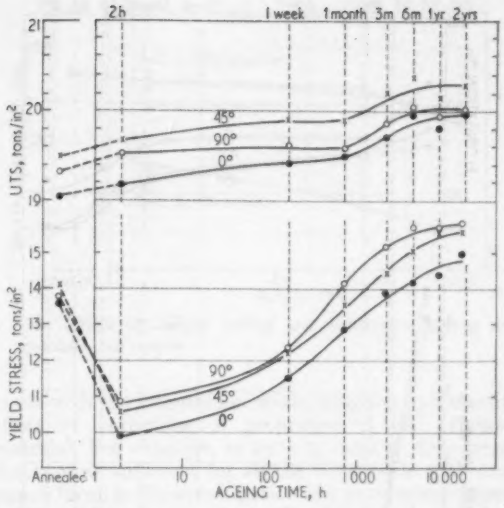
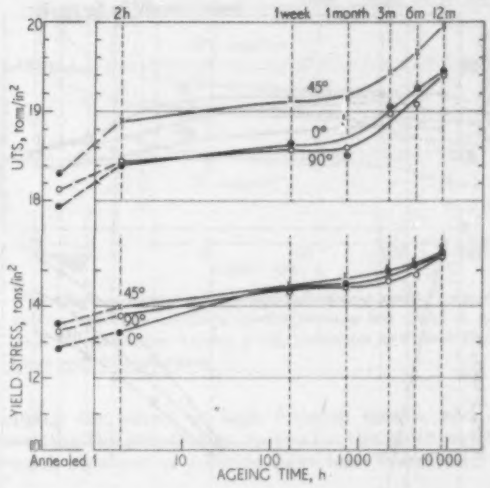



**1** *The effects of temper rolling 1·2% and subsequent ageing on the yield stress and ultimate tensile strength of steel* A, *at 0°, 45°, and 90° to the rolling direction*




**2** *The effects of temper rolling 5% and subsequent ageing on the yield stress and ultimate tensile strength of steel* B, *at 0°, 45°, and 90° to the rolling direction*

The most important metallurgical variables concerned with the effects of temper rolling and strain ageing are the rolling reduction, the dissolved interstitial solute content, and the grain size.[9–12] Theoretically, the best choice of temper rolling reduction for a particular application will depend on the grain size and the dissolved carbon and nitrogen contents. In practice the grain size and available interstitial solute content of commercial deep-drawing quality OH rimming steels do not vary very widely, and a temper rolling reduction of about 1% has been found suitable for most applications, in which ductility is generally of first importance. For this reason most of the tests in this investigation have been made on standard, commercially processed and annealed, deep-drawing rimming steels, temper rolled about 1¼%. A smaller number of tests have been made on one of the steels after 5% reduction in temper rolling (a strain in excess of Lüders strain in the annealed condition). Such a rolling reduction is much more effective in delaying the return of the sharp yield point on ageing, but at the expense of ductility.

The principal aim of the investigation has been to study those aspects of formability concerned with the limiting strains which may be applied, before the onset of plastic instability leading to fracture. Thus direct studies of the formation stretcher strains on ageing have been confined to measurements of Lüders strain in uniaxial tensile tests. In industry a return of the tendency to form stretcher strains, after normal periods of storage, can be satisfactorily suppressed by light roller levelling by the user. However, this could lead to a further reduction in ductility. A few tests have, therefore, been made on sheet lightly roller levelled in the aged and unaged conditions.

## EXPERIMENTAL METHODS

### Materials

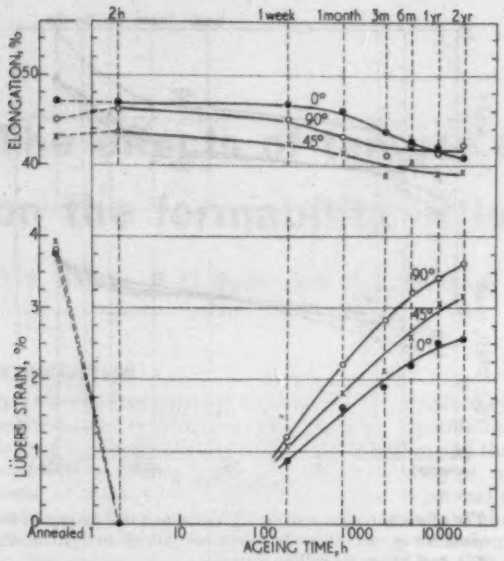
Deep drawing quality OH rimming steel sheets, manufactured from four different ingots, were used. With the exception of steel *C*, only bottom of ingot material was examined. Apart from the final temper rolling, all the sheets were rolled down and box-annealed by The Steel Company of Wales using standard industrial methods. Table I gives the chemical analyses, average grain sizes, thickness, and surface roughness of the different batches of sheet. Tensile properties in the 'as received', box-annealed, conditions are included in Table II and Figs.1–4.

### Temper rolling

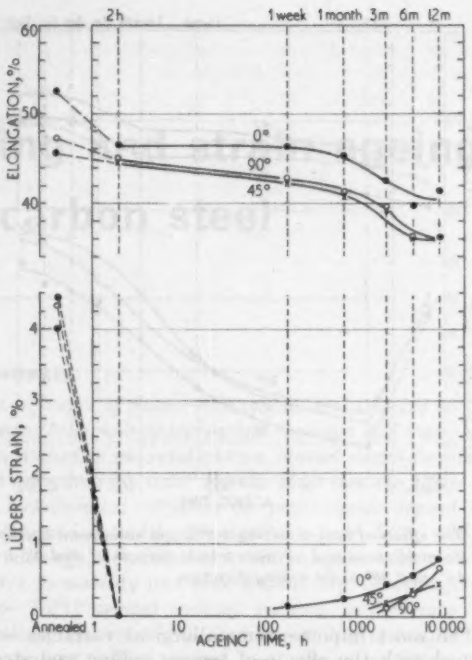
For most of the experiments temper rolling was carried out at 50 ft/min, in a 2-high laboratory mill

**TABLE I Chemical analyses, average grain sizes, thickness, and surface roughness of different batches of sheet**

| Ingot | | *A* | *B* | *C* | *D* |
|---|---|---|---|---|---|
| Sheet thickness, in | | 0·053 ±0·002 | 0·050 ±0·002 | 0·036 ±0·001 | 0·040 ±0·001 |
| *Samples for chemical analysis* | | Average of results with representative samples taken from the sheets | | | Pitside analysis |
| Chemical analysis in wt-% | C | 0·046 | 0·040 | 0·040 | 0·075 |
| | N | 0·0039 | 0·0041 | 0·0049 | ... |
| | Si | 0·011 | 0·012 | 0·003 | ... |
| | S | 0·025 | 0·015 | 0·026 | 0·024 |
| | P | 0·010 | 0·007 | 0·011 | 0·013 |
| | Mn | 0·27 | 0·37 | 0·33 | 0·36 |
| | Ni | 0·05 | 0·05 | 0·05 | 0·07 |
| | Cu | 0·09 | 0·05 | 0·09 | 0·07 |
| | Sn | 0·03 | 0·01 | 0·007 | 0·01 |
| | Soluble Al | <0·001 | 0·001 | <0·001 | ... |
| *Surface roughness*, μ inches CLA (Talysurf) | As annealed | 80–100 | 130–150 | 70–90 | 25–35 |
| | After temper rolling | 20–30 | 35–45 | 50–60 | 10–20 |
| Grain size, grains/mm² | | 2600 | 2200 | 3700 | ... |




**3** *The effects of temper rolling 1·2% and subsequent ageing on Lüders strain and total elongation (2in gauge length) of steel* A




**4** *The effects of temper rolling 5% and subsequent ageing on Lüders strain and total elongation (2in gauge length) of steel* B

with smooth 14in dia. rolls. Two rolling reductions, namely:

$1{\cdot}2 \pm 0{\cdot}1\%$

and $5{\cdot}0^{+0{\cdot}1\%}_{-0{\cdot}3\%}$

were used. With the exception of a single experiment, no roller levelling was applied after temper rolling steels *A* and *B*. It was not expected that the differences in surface finish (Table I) would have any important effect in drawability tests using graphitic lubrication but, to allow results to be compared with those obtained with industrially temper rolled material, a proportion of the sheets of steel *C* were temper rolled, to give about 1% reduction, at The Steel Company of Wales.

### Ageing

Strain ageing was carried out at room temperature (mean temperature 17·0°C), for periods up to 4 months. The longer treatments (up to the equivalent of about 2 years at room temperature), were completed by heating at $60 \pm 0{\cdot}3$°C in an oil bath. Equivalent ageing times were calculated using Hundy's equation.[13]

### Tensile tests

Tensile tests were made on strip specimens of 8in gauge length in the case of steel *C*, but otherwise standard specimens of 2in gauge length and 0·5in width were tested at a strain rate of $5 \times 10^{-4}$ s$^{-1}$ in a hard beam machine. During machining the specimens were immersed in a bath of soluble oil to minimize heating.

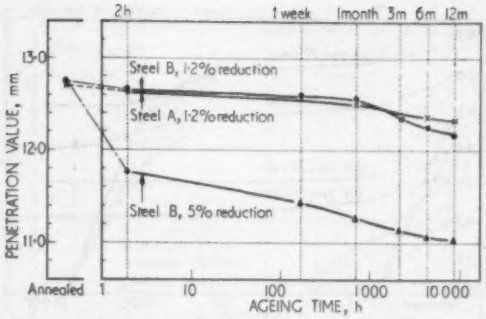
### Deep drawing tests

The double-action 'Swift' cupping press used for both the deep drawing and the large stretch-forming tests has been described previously.[14]

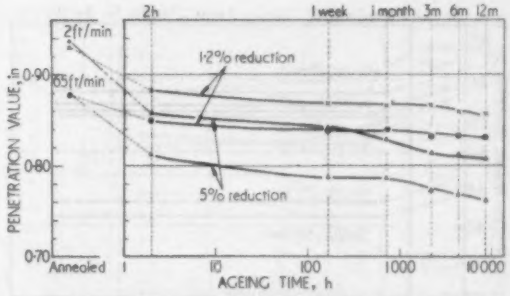
Three punches, all of 2in dia. but with 1in, $\frac{1}{2}$in, and $\frac{1}{8}$in profile radii respectively, were used in the drawing tests. To allow free drawing, the 0·05in thick material was drawn through a die of 2·172in dia. and the 0·04in thick material through a 2·125in dia. die. In both cases the die profile radius was $\frac{1}{8}$in. The tools were made from high-carbon high-chromium steel with radii carefully blended. Final polishing was standardized, using a diamond compound (Hyprez no.3/W/40). This gave a surface finish better than 5 $\mu$ inches CLA (Talysurf). Periodic redeterminations of the critical blank size of a standard annealed low-carbon steel showed there was no significant change in drawing performance throughout the period of the investigation.

Most of the drawing tests were made on 0·05in thick sheets of steels *A* and *B* using graphitic lubrication and a blank holder load of 2250 lb. The lubricant was Acheson's colloidal graphite in acetone, diluted 1:4. Degreased blanks were dipped in the suspension, removed vertically, allowed to dry, and finally polished with cotton wool, to give a thin, even layer of graphite. The main reason for using this lubricant was that, unlike liquid lubricants, its performance is insensitive to forming speed.[14] However, drawing tests were carried out on steel *C* using the oil lubricant (Esso TSD 996) recommended in the tentative specification for the Swift test. Drawing speeds of $2 \pm 0{\cdot}5$ and $65 \pm 3$ ft/min were used throughout the tests on steels *A* and *B*.

Drawing test results are given in terms of a 'critical' blank size, which is an estimate of the blank diameter for which there is an equal probability of success and failure, based on tests on a series of blanks differing in diameter by 0·05in increments. Either four (for steels *A* and *C*) or five (for steel *B*) blanks were drawn at each size in a given condition. Blank selection was




**5** *The effects of temper rolling and subsequent ageing on Erichsen test results*




**6** *The effects of temper rolling and subsequent ageing on penetration values in the large stretch-forming test. Steel* A *was used for specimens having 1·2% reduction and steel* B *for those with 5% reduction*

made with the intention of minimizing any systematic effect of variations in properties of the original material. For example, in tests on steel *A*, four large sheets were sufficient for all the tests made with one punch form, in the investigation of a particular temper rolling and ageing sequence. The four blanks making up a single size group, representing a particular condition, were selected one from each sheet in such a way that members of a single size group had representatives not only of the four sheets but also, as far as possible, of the edge, centre, front, and back positions within the sheets. A similar plan, based on a five-sheet scheme, was used in the case of steel *B*. With steels *A* and *B*, temper rolled in the laboratory, blanks used for tests in the annealed condition could be selected before temper rolling according to the scheme just outlined. In the case of Steel *C*, which was temper rolled in the factory, separate large sheets had to be used to represent the annealed and temper rolled conditions.

### Stretch-forming tests

Standard Erichsen tests were carried out on a Model 1 machine. The quoted values are the average of ten tests made on specimens selected in a similar manner to that used for the drawing tests. Graphitic lubrication, applied as in the drawing tests, was used in all the stretch-forming tests except those on steel *C*.

The large stretch-forming tests were made in the Swift cupping press. This test has been described in detail previously.[6] Biaxial stretch-forming was carried out over the same 2in dia. hemispherically nosed punch as was used in deep drawing. The specimens, in the form of 5in squares, were firmly clamped to prevent any draw-in beyond the periphery of a central circle of material 3·30in in dia. The punch speeds used were the same as those in the deep drawing tests. As with the Erichsen test, the criterion of performance was the punch penetration required to give the earliest indication of a clear crack. The methods used for stopping the punch at high forming speeds, and of correcting the penetration values for the finite widths of crack obtained in practice, have been described.[6]

## EXPERIMENTAL RESULTS

### Tensile tests

The results of uniaxial tensile tests made at 0, 45, and 90° to the rolling direction in the sheets in the annealed condition, after temper rolling and at various stages of ageing, are summarized in Figs.1–4 and Table II.

Most of the tests made after 1·2% temper rolling were on steel *A* and those after 5% reduction were on steel *B*, but results of tests made on steel *B* after 1·2% rolling reduction were only trivially different from those with steel *A*.

The effects of ageing on tensile properties were generally similar to those observed by previous investigators,[9–11] but present results illustrate more fully some of the directional effects in temper rolled and aged sheets and also allow a comparison with properties before temper rolling.

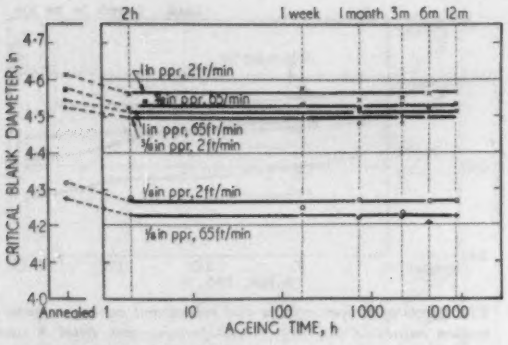
### Stretch-forming tests

Figure 5 shows the effects of temper rolling and ageing on the Erichsen values of the laboratory temper rolled sheets. In contrast to results with 5% temper rolling, the 1·2% reduction had only a very small effect on the Erichsen values. The decreases in ductility in the later stages of ageing were reflected in decreases in penetration value, but these were comparatively small in the 1·2% rolled material.

Results with the large stretch-forming test, using the laboratory temper rolled material and graphitic lubrication, are summarized in Fig.6. With this test an appreciable fall in stretch-formability occurred as a result of both 1·2% and 5% temper rolling but the effect of ageing after 1·2% temper rolling was again comparatively small. Stretch-formability was con-

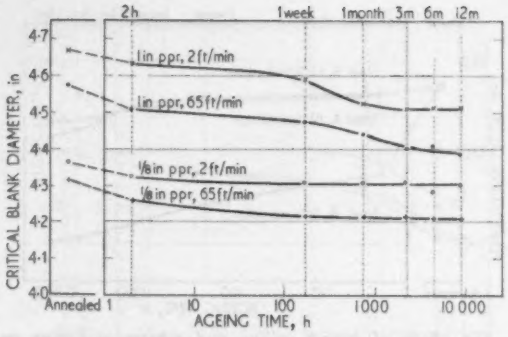
**TABLE II Tensile properties of steel *C* (bottom of ingot material)**

| Condition | As annealed | | | Temper rolled | | | Aged 6 months | | |
|---|---|---|---|---|---|---|---|---|---|
| Direction of test (degrees, relative to rolling direction) | 0 | 45 | 90 | 0 | 45 | 90 | 0 | 45 | 90 |
| Yield point, tons/in² | 16·4 | 17·1 | 16·3 | 11·9 | 13·1 | 13·0 | 15·4 | 16·3 | 16·1 |
| UTS, tons/in² | 19·4 | 20·1 | 19·5 | 19·7 | 20·7 | 20·3 | 20·8 | 21·3 | 20·7 |
| Elongation, % (8in gauge length) | 37 | 32·5 | 34 | 33·5 | 31 | 35 | 27·5 | 26·5 | 26·5 |
| Elongation, % (2in gauge length) | 50 | 46 | 50 | 48 | 44 | 48 | 43 | 40 | 42 |




ppr = punch profile radius

**7** *Effects of temper rolling 1·2% and subsequent ageing on deep drawability of steel* A




**8** *Effects of temper rolling 5% and subsequent ageing on deep drawability of steel* B

sistently less at a punch speed of 65 ft/min than at 2 ft/min when graphite lubrication was used, but, on the whole, the changes in penetration value due to temper rolling and ageing were insensitive to forming speed. In all cases fracture occurred nearer the pole of the pressing at the higher forming speed.

The scatter of results obtained with the large stretch-forming test was within $\pm 1{\cdot}5\%$ of the average value.

An important difference between Erichsen test results and those of the large stretch-forming test is in the change of penetration resulting from 1·2% temper rolling. The most important factor involved was probably the difference in clamping conditions. With the large test the area of material stretched was precisely limited to the area bounded by the clamping step. With the Erichsen test, on the other hand, considerable draw-in of material occurs over the flat face of the die. It was found that the area of the flange affected by draw-in was appreciably greater in 1·2% temper rolled sheets than in annealed sheets of the same steel: presumably this difference is related to the differences in yield stress. Probably the amount of draw-in occurring in Erichsen tests depends on the relation between the initial yield stress and the stress required to deform to fracture. (Results consistent with this possibility have been obtained in experiments with annealed low-carbon steel sheets of widely different grain size.) A dependence of draw-in on the yield stress/UTS ratio may not only reduce the apparent effect of 1·2% temper rolling in the Erichsen tests, but may also tend to enhance the effects of strain ageing on the penetration values in this test.

With steel *C* large stretch-forming tests were made using the liquid lubricant. In this case stretch-formability tended to improve with forming speed owing, primarily, to the improvement in lubrication at the higher strain rates. Despite this, the change in formability due to ageing was very similar to that observed in tests with graphitic lubrication. At the lowest strain rate (1·5 ft/min) the change in formability due to temper rolling was also similar to that with the solid lubricant, but in tests at 15 and 75 ft/min with the liquid lubricant the effect of temper rolling was less.

### Deep drawing tests

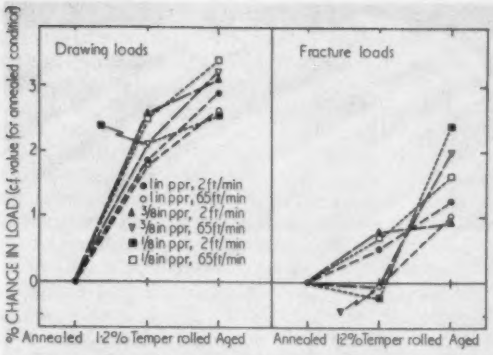
Figures 7 and 8 summarize the results of deep drawing tests made on steels *A* and *B*, using graphitic lubrication.

The critical blank size in drawing is dependent on punch form, lubrication, and drawing speed, but the observed changes in drawability due to a given change in drawing speed or a change in punch form were generally insensitive to the effects of both temper rolling and strain ageing. The results in Fig.8 provide the only important exception: strain ageing after 5% temper rolling caused an appreciable reduction in drawability when the hemispherically nosed punch was used, but had little effect with a punch of small profile radius. With this single exception strain ageing had a negligible effect on drawability with all the combinations of tool form, lubrication, and drawing speed examined.

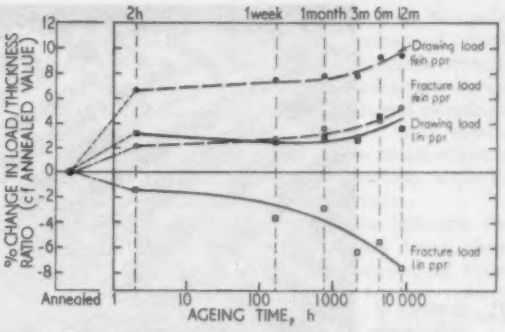
However, the drawability of temper rolled sheet was inferior to that of the annealed condition because temper rolling itself caused a reduction in drawability. This reduction was surprisingly insensitive to the process variables (Figs.7 and 8).

A small number of tests made on roller levelled sheet (Table III) suggested that light roller levelling applied soon after 1·2% temper rolling did not cause any significant further fall in drawing performance, nor did it affect drawability after subsequent ageing. However, it is possible that a similar roller levelling treatment applied to sheet which has suffered prolonged ageing, after temper rolling and before levelling, does reduce the drawability slightly. The degree of roller levelling applied was sufficient to suppress the yield point which developed after about one month's ageing at room temperature but was insufficient to suppress completely the sharp yield point developed in six month's ageing.

Experiments were made to examine the possibility that the changes in drawability observed to result from temper rolling were influenced by surface smoothness (Table I). Annealed blanks of steel *A* were polished with emery paper to give a surface roughness similar to that of the temper rolled material and the material was retested in the two conditions. Later smooth, annealed sheets of an extra deep drawing quality steel were obtained (steel *D*) and these were temper rolled without a marked change in the surface roughness. The change in drawability due to 1·2% temper rolling, observed with both these sets of blanks, was again a decrease of between one half and one increment in blank size (using graphitic lubrication and the punch of $\frac{1}{8}$in profile radius). It was concluded that differences in surface roughness had not made any important




**9** *Average values of the changes in maximum drawing loads and fracture loads, relative to values for the annealed condition, due to 1·2% temper rolling and full ageing. (Steels* **A** *and* **B**, *using graphitic lubrication. Results for 6 and 12 months ageing combined)*




**10** *Average values of the changes in maximum drawing loads and fracture loads, relative to values for the annealed condition, due to 5% temper rolling and subsequent ageing. (Steel* **B**, *with graphitic lubrication: results for the two drawing speeds combined)*

contribution to the changes in drawing performance observed in tests made with graphitic lubrication.

With respect to the effects of temper rolling and ageing, drawing test results on the factory temper rolled steel *C* were qualitatively similar to those on the laboratory rolled steels *A* and *B*. In this case also strain ageing after about 1% rolling had a negligible effect on drawability, but the temper rolling itself tended to reduce drawability slightly.

Strong speed effects were observed in drawing tests with the liquid lubricant on steel *C*. With a hemispherically nosed punch, increased drawing speed caused a marked reduction in drawing performance (a decrease of about 0·2in in critical blank dia. for a speed change of 1·5–115 ft/min), but with a punch of small profile radius there is an equally marked improvement with increased speed.

Drawing loads and loads at fracture were measured throughout the investigation. Since the effects of normal variations in blank thickness on loads are large compared with the small changes in drawing load that are significant in relation to drawing capacity, comparisons were made in terms of average-load/thickness ratios. Maximum drawing loads were compared at identical blank diameters near the critical. Fracture loads, which are influenced by the stage of punch penetration at which fracture occurs, were compared at the blank size nearest to the critical diameter. Some of these load results are summarized in Figs.9 and 10. Although the scatter is large compared with the load changes which have significant effects on drawability, the results suggest that the fall in drawability on temper rolling was due to an increase in maximum drawing load which was appreciably greater than the corresponding increase in fracture load. On strain ageing after 1·2% temper rolling the load changes were probably of comparable magnitudes. The conclusion that an unexpectedly large increase in drawing load occurs as a result of 1·2% temper rolling, was confirmed in an experiment designed to obtain accurate load measurements at the lower drawing speed. Sets of blanks of 4·40in and 4·70in dia. were selected within a narrow thickness range, in the annealed and temper rolled conditions, from the centre of one sheet of steel *B*. These were drawn using the hemispherically nosed punch and graphitic lubrication. The average increase in drawing load due to 1·2% temper rolling, with 4·40in blanks, was 3·1%. The fracture load, measured with the larger blanks, was practically unchanged.

**TABLE III** **Deep drawing tests on temper rolled and roller levelled steel *B* using a punch of 1in profile radius and graphitic lubrication, drawing speed 2 ft/min**

| | | Results of drawing tests *S*=successful, *F*=failure | | | |
|---|---|---|---|---|---|
| | Blank dia., in | 4·35 | 4·30 | 4·25 | 4·20 |
| *Pretreatment of material* | As annealed | 5 *F* | 2 *S* 3 *F* | 5 *S* | ... |
| | Temper rolled 1·2% | ... | 5 *F* | 3 *S* 2 *F* | 5 *S* |
| | Temper rolled and lightly roller levelled | ... | 5 *F* | 2 *S* 3 *F* | 5 *S* |
| | Temper rolled and aged for 6 months | ... | 5 *F* | 2 *S* 3 *F* | 5 *S* |
| | Temper rolled, roller levelled, and aged for 6 months | ... | 5 *F* | 3 *S* 2 *F* | 5 *S* |
| | Temper rolled, aged for 6 months and then roller levelled | ... | 5 *F* | 1 *S* 4 *F* | 5 *S* |

## ANALYSIS AND DISCUSSION OF RESULTS

The simple conclusion to be drawn from this work is that metallurgical changes such as temper rolling and strain ageing can affect performance in differing forming operations in distinctly different ways. A complete explanation of the ways in which some of the differences arise must await a satisfactory theoretical analysis of the development of strains and plastic instability in biaxial stretching over a metal tool, nevertheless it is possible to examine the principal factors involved in qualitative terms.

### Uniaxial tensile tests

So far as changes in uniaxial tensile properties due to strain ageing after temper rolling are concerned, present results are in good agreement with earlier work.[9–11,16] The increases in tensile strength and decreases in general elongation (Figs.1–4), which develop most strongly after ageing times in excess of 1 week, are believed to be due to the precipitation

11 *Evidence of unhomogeneous plastic strain on polished edge of a low-carbon steel strip after rolling 1·2%*

stage of solute segregation.[11,12] In the slowly cooled steels used, these effects are probably due almost entirely to the dissolved nitrogen (Table I). They increase with moderate increases in prestrain (probably because increased dislocation density gives a finer dispersion of precipitates), but they are not very sensitive to the mode of prestrain. On the other hand, the characteristics of the return of the sharp yield point and Lüders strain, with ageing after temper rolling, are quite different from those shown by specimens which have been prestrained by stretching.[10,12] Masking of the return of the sharp yield point in temper rolled sheet has been discussed by earlier investigators,[10,15,16] principally in terms of the influence of internal stresses and the Bauschinger effect. These explanations are not completely successful in accounting for some features of the return of the yield point in lightly temper rolled material, such as the directional characteristics illustrated in Figs.1–4. Probably insufficient account has been taken of the effects of the pattern of unhomogeneous plastic deformation developed in light temper rolling[17] (Fig.11). However, excepting its influence on the return of stretcher strain markings in sheets pressed after ageing, the return of the sharp yield point does not appear to have had any dominant influence on formability performances in present tests.*

Referring now to changes in tensile properties due to temper rolling itself; these show the familiar result that both 5% and 1·2% reductions are successful in eliminating the sharp yield point. Unlike the heavier reduction, 1·2% temper rolling causes a considerable reduction in yield stress. We believe this is associated with easy nucleation of yield at the interfaces of blocks of yielded and unyielded material, similar to those illustrated in Fig.11. After 5% reduction the whole of the material is strained plastically and this effect does not occur.

A more unexpected feature of the tests was that 1·2% temper rolling caused no decrease in the average elongation to fracture; in fact elongation values in tests at 45° and 90° to the rolling direction improved slightly (Fig.3). The effect is small and is observed only if precautions are taken to avoid ageing the specimens during machining. It is probably due to a small enhancement of the initial work hardening rate, possibly associated with the unusual deformation pattern produced by light temper rolling (Fig.11).

### Effects of temper rolling and strain ageing on stretch-forming performance

As in uniaxial tests, in biaxial stretch-forming the work hardening behaviour of the metal is expected to play a principal role in determining the overall strains at which plastic instability develops. The effects of temper rolling and of strain ageing on stretch-formability are therefore expected to show qualitative similarities to their effects on general elongation in uniaxial tests. Broadly speaking, present results show this to be the case: for example, the changes in stretch-formability due to strain ageing, after 1·2% and 5% temper rolling, follow essentially the same pattern as the corresponding changes in ductility observed in tensile tests (Figs.3–6). However, the effects of ageing on performance in stretch-forming were relatively small in the more lightly temper rolled material.

From a practical viewpoint the results of greatest interest are those in which simple tensile tests fail to give a reliable indication of relative performances in biaxial stretching. Thus the decrease in formability due to 1·2% temper rolling would not be predicted from the uniaxial elongation measurements (Fig.3). (In stretch-forming and deep drawing, fracture was generally initiated in a direction parallel to the original rolling direction, i.e. across the 90° direction of testing with respect to uniaxial tests.) It has been suggested that the lack of a fall in elongation values, in the case of tensile tests on the 1·2% rolled sheets, is due to a small enhancement of the initial work hardening rate associated with the particular deformation sequence; so that, at test strains of about 0·3 (at which plastic instability develops in the uniaxial tests), the work

* However, drawing tests made using progressive reductions in blankholder pressure showed that the rise in yield stress on ageing increased the tendency to wrinkle. In practice this can decrease formability since, if increased blankholder pressure is required, it may increase strains in the stretch-formed zone of the pressing.[7]

hardening rate of previously temper rolled material is not inferior to that of annealed specimens. Results with the large biaxial stretch-forming test suggest that such an initial enhancement of the work hardening rate after 1·2% temper rolling is not maintained at the much greater thickness strains (often about 0·5), at which plastic instability develops in biaxial stretching. This result illustrates the fact that, when work hardening rates are used to predict relative stretching performances, the comparisons should be made within the relevant ranges of straining.

While it is possible to explain the qualitative effects of temper rolling and ageing on stretch-formability as a consequence of reductions in work hardening at high thickness strains, any more detailed analysis of the results must take account of the combined effects of the mode of straining and of friction. In biaxial stretching of a circular sheet over a hemispherical tool, yielding starts at the centre and spreads outwards as the central region continues to strain and to work harden. Flow of material coming into contact with the tool is restrained by friction. Starting at the centre, an increasing area of the pressing is affected in this way as punch penetration develops. For this reason the region of maximum thickness strain tends to move outwards from the pole as general straining increases. This process is interrupted when work hardening at some point in the region of high thickness strain ceases to be sufficient to allow any further increase in load. With the development of plastic instability, further deformation becomes localized and soon leads to fracture. A wide range of thickness strains is developed in the final pressing and it is clear that, while the work hardening rate at high thickness strains is of first importance, the overall stretching performance will be influenced by the whole of the work hardening behaviour from yield point to fracture (*see* Figs.11–13 of ref.6).

It was observed that differences in yield point behaviour, in the annealed and 1·2% rolled conditions, affected the development of strains. In the early stages of stretch-forming yielding in the temper rolled material spread further towards the periphery, presumably as a result of its lower yield stress. However, this initial advantage of the temper rolled material was evidently outweighed in the later stages of deformation by the effects of inferior work hardening at high thickness strains. This is expected to cause plastic instability to develop at a lower punch penetration and to cause the neck to move inwards toward the pole, as was observed. Effects related to yield point behaviour may be more important when frictional restraints are relaxed, so that strains can develop further in the central regions of the pressing. Stretch-formability tests made using the liquid lubricant at low speeds showed a reduction in formability due to temper rolling which was similar to that obtained using graphitic lubrication; but at high speeds (which give low friction, with fracture close to the pole and strong yield points), the fall in penetration due to 1·2% temper rolling was small.

Strain ageing increases the yield stress and the initial rate of work hardening of temper rolled sheets, although work hardening rates at high thickness strains tend to be reduced. Measurements of thickness strains showed that, as strain ageing developed in the 1·2% temper rolled material, thinning in the central region of the stretch-formed test pieces was reduced and the neck tended to move outwards from the pole. These observations suggest that enhanced work hardening at comparatively low thickness strains tended to exert a small, favourable influence on the final distribution of strains in the fractured pressings. This behaviour may underlie the fact that strain-ageing, after 1·2% rolling, has a rather small effect in the stretch-formability test in comparison with its effect on uniform elongation in tensile tests.

Despite the considerable differences between the Erichsen and the large stretch-forming tests, their results agree fairly well with the exception of those concerned with the effects of 1·2% temper rolling. This difference appears to be primarily a consequence of the difference in clamping conditions (*see* 'Experimental results') and suggests that the two tests apply to rather different conditions of stretch-forming.

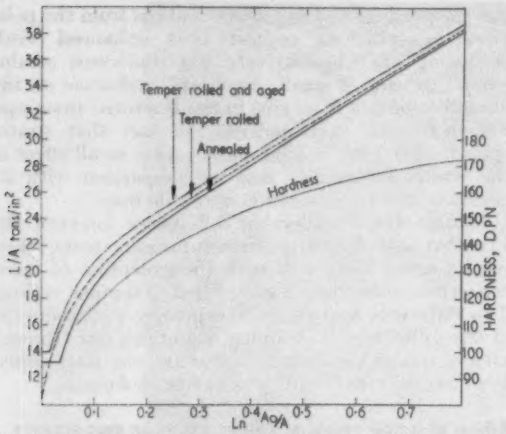
#### Effects of temper rolling and strain ageing on deep drawing

A comparison of the drawing results with those of other tests provides support for Swift's contention that predictions of deep drawing performance must be based on simulative tests. Conventional tensile tests suggest that 1·2% temper rolling itself has a negligible effect on ductility, but that ductility decreases appreciably during subsequent strain ageing (Fig.3). The deep drawing tests show, on the contrary, a significant drop in drawability due to temper rolling 1·2% and no change due to ageing this material, irrespective of punch form (Fig.7). No simple criterion based on the nominal stress–strain curve, such as the YS/UTS ratio would predict this result. However, results with the 5% temper rolled material show that a more severe change in properties due to strain ageing can affect drawability if the operation is one which involves a large stretch-forming component (Fig.8).

Disparities are less extreme between the results in biaxial stretch-forming and in deep drawing. Fracture in drawing occurs in the base of the cup, which is deformed under conditions more or less similar to those in a stretch-forming test. However, the drawing test is concerned not so much with ductility as with the strength developed in the base (more precisely, with the ability of the stretched base to support the maximum load required for drawing).

A reduction in work hardening rate at high thickness strains will tend to reduce stretch-formability. It can be argued that a similar reduction in the possible extent of stable thinning in the stretch-formed zone of a drawn cup will limit work-strengthening of the base, and consequently reduce permissible strains in the drawing zone. This type of qualitative argument has been advanced to support the idea that behaviour in drawing operations which involve a large stretch-forming component should correlate with stretch-forming test results. When stretch-forming in drawing is restricted, by using a punch having a small profile radius, the thinning which develops at the critical base neck[3] is more dependent on the geometrical factors affecting strains in bending and less strongly influenced by the work hardening behaviour of the material. Thus drawing performance becomes less sensitive to work hardening characteristics as the punch profile radius is reduced.

In the case of the 5% temper rolled material drawn with the hemispherically nosed punch, the observed changes in drawability due to rolling and ageing do




**12** *Derived stress–strain curves for the annealed, temper rolled 1·2%, and temper rolled and aged for 6 months conditions. (L is the load in tons and Ao and A the original and instantaneous areas, respectively). The curves are drawn through mean values of tests taken at 0°, 45°, and 90° to the rolling direction*

follow the same pattern as the corresponding changes in stretch-formability (Figs.6 and 8). The same material showed a negligible fall in drawability due to ageing when drawn with a punch of small profile radius: a result consistent with the idea that differences in work hardening are relatively unimportant when a small profile radius is used. However, on the basis of these simple arguments, it is not possible to account for the reductions in drawability due to temper rolling which were also observed with this punch. A similar difficulty is met in the case of the 1·2% temper rolled material drawn on the hemispherically nosed punch (Fig.7).

An obvious shortcoming of predictions of drawability based directly on stretch-formability results is that the effects of possible differences in plastic behaviour in the stretch-formed and drawing zones are neglected. In drawing, previous strengthening of the metal by working or ageing will increase both the drawing load and the load required to fracture the base. To a first approximation these load changes compensate each other. A decrease in critical blank size will occur only when the increase in drawing load exceeds the corresponding increase in fracture load. A comparison of load measurements (Figs.9 and 10) with drawability results (Figs.7 and 8) illustrates the controlling influence of the *relative* changes in drawing loads and fracture loads.

Changes in plastic anisotropy within the sheets can give rise to changes in relative work hardening behaviour in the stretch-formed and drawing zones of a deep drawn component.[6] For this reason drawability is found to correlate with $R$ coefficients measured in tensile tests, even though, with flat-bottomed cups, it is rather insensitive to average strain hardening rates.[18] ($R=\frac{\ln (W_0/W_u)}{\ln (t_0/t_u)}$, where $W_0$ and $t_0$ are the initial width and thickness dimensions and $W_u$ and $t_u$ are the width and thickness after straining in the regime of uniform elongation. Thus $R$ coefficients provide an indication of plastic anisotropy in the thickness direction of the sheets.)

**TABLE IV Plastic anisotropy ($R$) coefficients of steel $B$**

$$R=\frac{\ln W_0/W_u}{\ln t_0/t_u}$$

| Direction of test relative to rolling direction | 0° | 45° | 90° |
|---|---|---|---|
| As annealed | 1·16 | 0·91 | 1·53 |
| Temper rolled 1·2% | 1·26 | 0·94 | 1·65 |
| Temper rolled 1·2% and aged 6 months | 1·19 | 0·95 | 1·54 |
| Temper rolled 5·5% | 1·13 | ... | 1·60 |
| Temper rolled 5·5% and aged 6 months | 1·15 | ... | 1·58 |

It is clear from Table IV that any small changes in $R$ coefficients due to temper rolling and ageing are quite insufficient to account for the observed variations in drawability. Evidently the causes of these variations must be sought in some other characteristic underlying the work hardening behaviour. It is of practical interest to test how far true (uniaxial) stress–strain relationships can provide the necessary, detailed information on work hardening rates, since these, like the $R$ coefficients, can be derived from simple tensile tests taken in representative directions in the sheet. This was examined in the case of material temper rolled 1·2%, the drawing behaviour of which is seemingly paradoxical.

Figure 12 gives tensile stress–strain curves derived from tests made at a strain rate of $10^{-4}$ $s^{-1}$. Since we are concerned with relative strain hardening behaviour no corrections have been made for the effects of the hydrostatic component of stress in the neck. Tests were made at 0°, 45°, and 90° to the rolling direction in adjacent strips taken from a single sheet, which were in the following conditions: annealed, 1·2% temper rolled, and 1·2% temper rolled and aged for the equivalent of 6 months at room temperature. The plotted curves for each condition are averages of the results obtained in the three directions of testing.

The ranges of strain hardening relevant to failure in drawing were identified by hardness testing, using an annealed blank of critical size which was drawn, using the hemispherically nosed punch and standard conditions, just to the point of maximum drawing load. Maximum hardness (166 to 172 DPN) occurred at the ring of maximum thinning in the base, which had just reached the point of plastic instability. The maximum load which could be supported would be determined principally by the strength of the base at this point. The required maximum drawing load would depend on the flow stress of material moving inwards over the die at this stage of the operation. Hardness in the flat flange ranged from 137 to 149 DPN and increased to a mean value of about 160 DPN in moving round the die radius. The relation between indentation hardness and strain measured in tensile specimens is given in Fig.12. Hardness values reached in the flat flange of the cup at maximum drawing load correspond to those reached at strains of 0·25–0·45 in tensile stretching, while the hardness at the point of critical thinning in the base was reached in the tensile test only after a strain of about 0·7.

Figure 12 shows that in the higher ranges of strain hardening, relevant to conditions at maximum load in the drawing test, ageing after 1·2% temper rolling had only small effects on the strain hardening rate. The stress–strain relationships were compared at tensile strains of 0·35 and 0·7. Neglecting the frictional com-

ponents of the loads, this comparison suggests that ageing will increase the drawing load by about 1·5% and the fracture load by about 1·1% relative to the freshly temper rolled condition. The relative increase in drawing load predicted is thus only about 0·4%. The change in drawing load for one increment in blank size near the critical size is 2·2% (an average value taken from numerous load measurements). Thus, unlike the simple comparisons discussed previously, the derived stress–strain curves can be used to predict that the change in drawability due to ageing after 1·2% temper rolling will be small compared with one increment in blank size, as observed. Moreover the predicted load changes are in reasonable agreement with experimental values.

Prediction of the effect of temper rolling is less successful. The relationships in Fig.12 suggest that, relative to the annealed condition, 1·2% rolling should increase the drawing load by about 1·3% and the fracture load by about 0·6%; a relative change which would give a fall in drawability of about one-third of an increment in blank size. Average observed values were an increase of 2·2% in drawing load and 0·3% in fracture load, giving a fall in drawability of almost one increment. Possibly, after light temper rolling, work hardening in drawing is slightly greater than in stretching but the measured differences are too small to allow a certain conclusion.

It has been shown that light temper rolling gives an unexpectedly large increase in drawing load without giving a corresponding increase in fracture strength (*see* 'Experimental results'). It is also evident that this change is not associated with a change in plastic anisotropy measured by the $R$ coefficient. Unusual work hardening behaviour could be associated with a change in the mode of strain: from rolling to stretching or to drawing. Possibly the unhomogeneous plastic deformation imposed by light temper rolling promotes this tendency. Such an effect would be most prominent at relatively low plastic strains in the second deformation.

The fact that the fall in drawability due to temper rolling is associated primarily with a change in behaviour affecting the drawing zone, rather than the stretch-formed zone, probably explains its insensitivity to punch form (Fig.7).

### Speed effects

The effects of changes in forming speeds (in the range 1·5–115 ft/min), on performances in deep drawing and stretch-forming, were often far greater than effects due to temper rolling and strain ageing. The principal causes of the speed effects are changes in the plastic behaviour of the metal with strain rate and changes in the effectiveness of a liquid lubricant with tool speed. However, in deep drawing the results of these changes depend strongly on tool form.[6,14] Present results are in good agreement with earlier conclusions and will not be discussed here.

The most important new conclusion, for present purposes, is that, within the range of conditions examined, the speed effects were rather insensitive to the changes in properties due to temper rolling and strain ageing. This result implies that the essential relative differences in plastic behaviour, between the differing metallurgical conditions, were preserved at the different strain rates examined.

## CONCLUSIONS

The following conclusions, suggested by this work, relate to deep drawing quality OH rimming steel sheets, having the chemical analyses given in Table I, which have been box-annealed and slowly cooled before temper rolling.

1. The ways in which temper rolling and strain ageing affect formability depend on conditions imposed by the particular operation. In general it is not possible to make reliable predictions of performance in one type of operation by using the results of a test which involves an essentially different mode of straining.

2. 5% temper rolling reduces general elongation in a uniaxial tensile test but 1·2% rolling reduction does not. Both these temper rolling reductions decrease performance in biaxial stretch-forming and deep drawing tests. In the case of stretch-forming the effects of 5% reduction are appreciably more severe than those due to 1·2% reduction.

3. Strain ageing after 1·2% rolling reduction reduces uniaxial tensile ductility and stretch-formability, but deep drawing performance is not significantly affected. After 5% rolling the effects of ageing on the stretching properties are more severe. Performance in a deep drawing operation which invovles a large stretch-forming component of deformation is also reduced by ageing after 5% reduction, but deep drawing results with a punch of small profile radius remain practically unaffected. These results show that the practical importance of a loss in tensile ductility due to strain ageing depends principally on the magnitude of the stretch-forming component of deformation in the operation concerned.

4. An analysis of the stretch-forming and drawability results suggests that the changes in performance, due to temper rolling and strain ageing, can be explained qualitatively in terms of their effects on work hardening rates. In general, changes in the work hardening rates at high plastic strains had a stronger effect on the formability test results than changes in the yield point and at low strains. However, uniaxial stress–strain relationships do not necessarily provide a sufficient basis for predicting relative performances in complex forming operations.

5. Predictions of deep drawing performances from more general measurements of plastic properties present a special difficulty because changes in drawability depend on changes in the relative magnitudes of the drawing load and the load required to cause plastic instability in the base. Deep drawability is, therefore, insensitive to general changes in plastic properties except in so far as these affect behaviour in the drawing zone and the stretch-formed zone differently. Temper rolling and strain ageing do not cause any important changes in the $R$ (plastic anisotropy) coefficients of the sheets, thus their effects on drawability, which are generally small, can be ascribed to their influences on work hardening characteristics.

6. Speed effects observed in drawing are related to changes in plastic behaviour of the material with strain rate, but they are also strongly dependent on tool shape and on lubrication effects. In deep drawing, the importance of the process variables, including drawing speed, and the complexity of their interactions, provide strong arguments in support of the use of simulative tests.

**ACKNOWLEDGMENTS**

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**REFERENCES**

1. J. D. Jevons: 'The Metallurgy of Deep Drawing and Pressing', 502–538; 1940, 1st ed., London, Chapman and Hall.
2. H. W. Swift: *Sheet Metal Ind.*, 1954, **31**, 817–828.
3. G. Murray: *ibid.*, 1958, **35**, 657–675.
4. G. de Witte: *ibid.*, 1960, **37**, 565–571.
5. K. Yoshida: *Sci. pap. IPCR* (Japan), 1959, **53**, 126–187.
6. D. V. Wilson *et al.*: *Sheet Metal Ind.*, 1961, **38**, 25–42.
7. R. Pearce: *ibid.*, 1960, **37**, 523–534.
8. D. K. O. Ullmann and V. M. Thomas: *ibid.*, 1960, **37**, 640–690.
9. A. J. K. Honeyman: *ibid.*, 1957, **34**, 51–65.
10. H. P. Tardif and C. S. Ball: *JISI*, 1956, **182**, 9–19.
11. B. B. Hundy: *Metallurgia*, 1956, **53**, 203–211.
12. D. V. Wilson and B. Russell: *Acta Met.*, 1960, **8**, 468–479.
13. B. B. Hundy: *JISI*, 1954, **178**, 34–38.
14. H. T. Coupland and D. V. Wilson: *Sheet Metal Ind.*, 1958, **35**, 85–108.
15. N. H. Polakowski: *JISI*, 1952, **172**, 369–376.
16. B. B. Hundy: *ibid.*, 1954, **178**, 127–138.
17. B. B. Hundy: *ibid.*, 1955, **181**, 313–315.
18. R. L. Whiteley: *Trans. Amer. Soc. Met.*, 1960, **52**, 154–163.

# Activities in lime–alumina melts

*R. A. Sharma and F. D. Richardson*

**SYNOPSIS**

*Measurements have been made of sulphide capacities and of the limiting solubilities of calcium sulphide in melts containing lime and alumina at 1500°C. A gas+slag equilibrium technique was employed. From these results, and thermal data concerning crystalline calcium aluminates, the activities of lime and alumina have been obtained over the whole liquid range.* 1944

ACTIVITIES in lime+alumina melts have been estimated in different ways by Fincham and Richardson,[1] Carter and Macfarlane,[2] and Chipman.[3] In the first two methods, use was made of the measured sulphide capacities, defined as $C_S = \text{wt-}\%S(p_{O_2}/p_{S_2})^{\frac{1}{2}}$. In the third, the lime activities were deduced by combining thermal data for the crystalline aluminates with the sulphide capacity data.

The uncertainties of all these estimates arise from a lack of knowledge of the activity coefficients of calcium sulphide in the melts. Fincham and Richardson[1] assumed a value of 5 for the solid sulphide in all the melts at 1650°C. Carter and Macfarlane found a value for the function

$$\%S(p_{O_2}/p_{S_2})^{\frac{1}{2}}$$

at 1500°C for the slag 60·6 wt-%CaO, 32·4%$Al_2O_3$, 7%$SiO_2$, and then for a series of CaO+$Al_2O_3$ mixtures. From the CaO+$Al_2O_3$+$SiO_2$ phase diagram, it is known that the lime activity in the first melt is unity at 1500°C. If it is assumed that the activity coefficient of CaS is the same in all the melts investigated, one can write

$$a_{CaO} = \%S\left(\frac{p_{O_2}}{p_{S_2}}\right)^{\frac{1}{2}}_C \Big/ \%S\left(\frac{p_{O_2}}{p_{S_2}}\right)^{\frac{1}{2}}_S$$

where the subscript $C$ denotes the lime+alumina slag and the subscript $S$ the standard slag in which the lime activity is unity. Unfortunately, this assumption is almost certainly in error, for recent work by one of the authors[4] has shown that the activity coefficient of manganese sulphide in MnO+$SiO_2$ melts increases by a factor of at least 3 as the mole fraction of MnO falls from 0·72 to 0·48.

In view of these difficulties, measurements have been made of the limiting solubility of calcium sulphide in CaO+$Al_2O_3$ melts at 1500°C, and at the same time the sulphide capacities have been measured. To this end, samples of slag have been brought into equilibrium with gas mixtures developing known partial pressures of oxygen and sulphur. These mixtures consisted of varying proportions of $CO_2$ and $H_2$ containing 1%$SO_2$ and 50%$N_2$. The preparation of the materials, the equilibrium technique and the analyses were almost precisely as already described by Fincham and Richardson.[1]

**RESULTS**

For each composition, experiments were made at increasing ratios of $H_2$:$CO_2$. The results are represented in Fig.1. This shows a series of plots of the logarithms of the weight percentages of sulphur found in different slags held for 7 h in flowing gas mixtures, each containing 1%$SO_2$, 50%$N_2$, and varying proportions of $H_2$ and $CO_2$. The extensions to each curve lead to points which lie beyond the top edge of the diagram. For each slag the sulphur contents increase smoothly with the ratio $pH_2/pCO_2$, until a gas composition is reached at which the sulphur content increases

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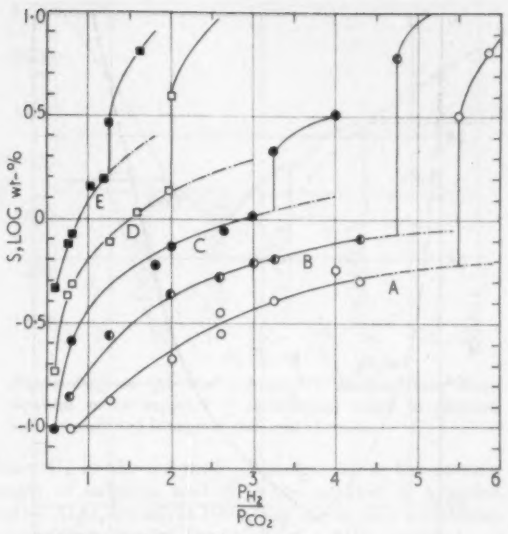



*Initial composition, wt-%*

| | CaO | $Al_2O_3$ |
|---|---|---|
| *A* | 42 | 58 |
| *B* | 45 | 55 |
| *C* | 48·2 | 51·8 |
| *D* | 52 | 48 |
| *E* | 56 | 44 |

**1** *The logarithms of the wt-% of S found in various slags at 1500°C for different ratios of $H_2$ to $CO_2$ in the presence of 1%$SO_2$ and 50%$N_2$. Some points in which saturation was exceeded lie beyond the top edge of the diagram*

suddenly.* This increase is caused by the formation of a free phase of calcium sulphide. The dashed extension of each full curve shows the form that each would take, if saturation with calcium sulphide did not occur. The limits of saturation with CaS clearly lie in each case between the last point on the full curve and the point at which the extension cuts the vertical dropped from the point lying far above the curve. Figure 2*a* shows the wts-% of sulphur at saturation plotted as a function of the mole fraction of lime present in the slag *before* pick-up of sulphur. The lower point for each composition is the last experimental point before saturation was reached. The upper point is that obtained from the intersection of the dotted extrapolation and the full vertical line. Figure 2*b* shows the saturation limits on the ternary composition diagram. The activity coefficients of CaS relative to the pure solid are shown in Fig.3 as a function of composition. Values for the saturation limits and the CaS activity coefficients are listed in Table I. Uncertainties in the measurements were the same as those already quoted by Fincham and Richardson.[1] The saturation limits are considered to be accurate to within ±0·05 wt-%. Table I also shows the sulphide capacities, wt-%S $(p_{O_2}/p_{S_2})^{\frac{1}{2}}$, of the melts: they were found to be independent of sulphur concentration from high dilution to saturation. The reproducibility of these values is ±5% and they agree with other published data.[5]

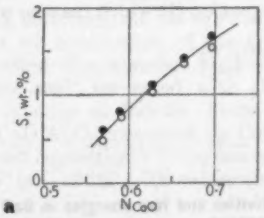
**TABLE I CaS saturation limits and $C_S$ values for $CaO+Al_2O_3$ melts at 1500°C**

| $N_{CaO}$ before experiment | Wt-% sulphur at saturation | Activity coefficient CaS | Sulphide capacity $C_S \times 10^3$ |
|---|---|---|---|
| 0·57 | 0·58 | 72·5 | 0·32 |
| 0·59 | 0·77 | 55·3 | 0·50 |
| 0·63 | 1·07 | 40·7 | 0·89 |
| 0·66 | 1·38 | 32·2 | 1·86 |
| 0·70 | 1·62 | 28·0 | 3·42 |

## DISCUSSION

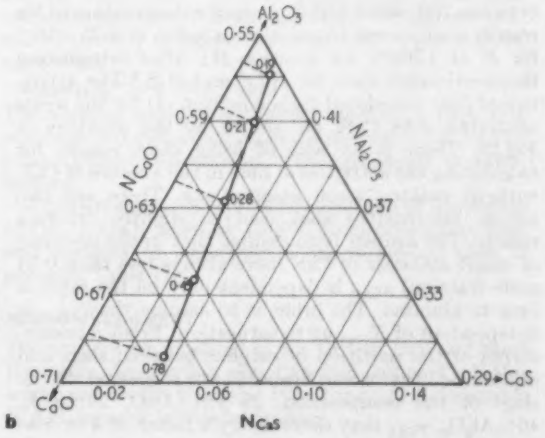
The manner in which the activity coefficient of CaS changes with the proportions of lime and alumina is shown in Fig.3. The variation is comparable with that already found for MnS, at low concentrations, in $MnO+SiO_2$.[4] In view of this, it is evident that the activity coefficient should not be taken as constant over wide ranges of composition, even for approximate calculations of lime activities from sulphide capacities. One would expect molten CaS to behave ideally in CaO, because molten FeS appears to behave ideally in FeO.[6] One would thus expect the activity coefficient of

* It can be shown by calculation from the lime activity values actually obtained, that for a 10% increase of $(p_{S_2}/p_{O_2})^{\frac{1}{2}}$ in the gas phase, beyond the saturation condition, free CaS should form in the slag until ultimately some 8–9%S is absorbed. The increase in S content for a similar change in gas composition just below the saturation limit would be only 0·16% when the mole fraction of lime is 0·70, and 0·06% when it is 0·57.




a

**2**(a) *Saturation solubility of S obtained in $CaO+Al_2O_3+CaS$ melts at 1500°C. $N_{CaO}$ is the mole fraction of CaO in the original melt and thus equal to $N_{CaO}+N_{CaS}$ in the final mixture. Upper limits filled circles; lower limits open circles* (see text), *and* (b) *Full line shows the saturation limits for CaS in the system $CaO+Al_2O_3+CaS$ at 1500°C. The numbers opposite each point are the derived activities of lime relative to the solid*

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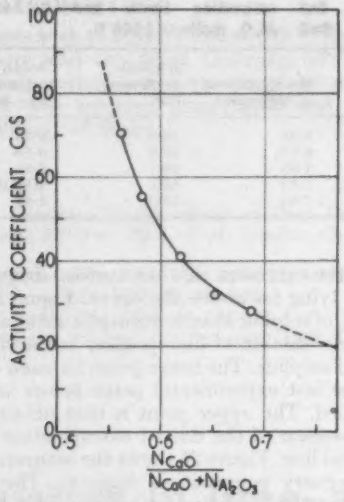



**3** *The activity coefficients of* CaS *at saturation relative to the solid at 1500°C in* $CaO+Al_2O_3+CaS$ *melts*

solid CaS to extrapolate, when $N_{CaO}$ is equal to unity, to a value given by the equation

$$1773\ R\ \ln \gamma_{CaS}=(T_m-1773)\ \Delta S_f$$

where $T_m$ is the melting point of CaS and $\Delta S_f$ is its entropy of fusion. Unfortunately $T_m$ is not known, and there are no reports of CaS having been melted. Analogy with other sulphides suggests that $\Delta S_f$ must be about 5 cal $deg^{-1}$ $mole^{-1}$; thus the curve for $\gamma_{CaS}$, which could be extrapolated to a value of 5 or 10, is compatible with a not unreasonable value of 2600–3100°C for the melting point.

The relationship between the activities of lime and calcium sulphide in any slag are given by the equation

$$K=\frac{a_{CaS}}{a_{CaO}}\left(\frac{p_{O_2}}{p_{S_2}}\right)^{\frac{1}{2}} \qquad \text{.....(1)}$$

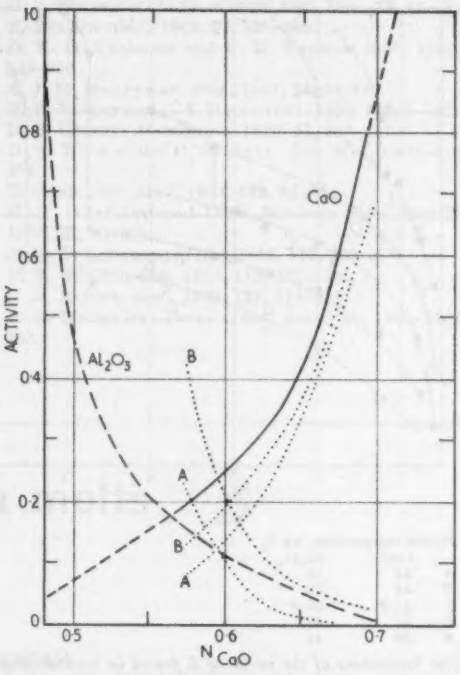
where $K$ is the equilibrium constant at 1500°C for the pure phase reaction

$$CaO+\tfrac{1}{2}S_2=CaS+\tfrac{1}{2}O_2 \qquad \text{.....(2)}$$

Fortunately this has been accurately established by Rosenqvist[7] who studied the equilibrium

$$CaO+H_2S=CaS+H_2O$$

between 750° and 1425°C. A small extrapolation of his results enables one to calculate a value of $2{\cdot}75\times10^{-3}$ for $K$ at 1500°C for reaction (1), after introducing thermodynamic data for $H_2O$[8] and $H_2S$.[9] The activities of lime calculated from equation (1) for the melts saturated with CaS, are shown by the numbers in Fig.2*b*. There is no way of using these results for calculating the activities of lime in the absence of CaS, without making some assumptions. There are two simple alternatives that lead to slightly different results. The simpler is to assume that in the presence of small amounts of CaS (here always less than 0·04 mole fraction) $a_{CaO}$ is dependent only on the ratio of lime to alumina. The other is to assume that $\gamma_{CaS}$ is independent of $N_{CaS}$ up to saturation. From measurements of the partition of sulphur between slags and liquid iron, Taylor and Stobo[10] have suggested that in slags of the composition, 28 wt-%CaO, 26%$SiO_2$, 46%$Al_2O_3$, $\gamma_{CaS}$ may decrease by a factor of 4 or 5 as




**4** *Activities in* $CaO+Al_2O_3$ *melts at 1500°C; full line, lime relative to solid; broken lines, lime extrapolations and derived alumina activities relative to solid; lightly dotted lines:* A *as derived by Carter and Macfarlane*[2] *assuming* $\gamma_{CaS}$ *constant;* B *as derived by Chipman*[3]

its concentration rises from zero to about 1% by weight. However, the results of these authors require that the sulphide capacities, as defined here, increase markedly as sulphur displaces oxygen in the slag, whereas in this work it has been found that CS is virtually independent of sulphur concentration. The conclusion of Taylor and Stobo concerning the change of $\gamma_{CaS}$ with sulphur concentration is thus in doubt, at least in so far as melts of $CaO+Al_2O_3+CaS$ are concerned. Since $C_S$ is independent of sulphur concentration, along any horizontal composition line in Fig.2*b*, i.e. as sulphur displaces oxygen in a $CaO+Al_2O_3$ mixture, the ratio $a_{CaO}/\gamma_{CaS}$ must be constant. This follows from equation (1) which may be written:

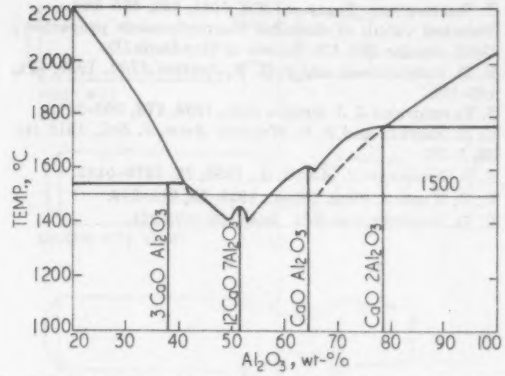
$$a_{CaO}=\frac{N_{CaS}\ \gamma_{CaS}}{K}\left(\frac{p_{O_2}}{p_{S_2}}\right)^{\frac{1}{2}} \qquad \text{.....(3)}$$

Thus

$$a_{CaO}=\frac{C_S\gamma_{CaS}}{32NK} \qquad \text{.....(4)}$$

**TABLE II Activities and free energies in $CaO+Al_2O_3$ melts at 1500°C**

| $N_{CaO}$ | $a_{CaO}$ | $a_{Al_2O_3}$ | $-\Delta G$ kcal |
|---|---|---|---|
| 0·58 | 0·21 | 0·15 | 6·04 |
| 0·60 | 0·25 | 0·115 | 5·99 |
| 0·62 | 0·30 | 0·085 | 5·92 |
| 0·64 | 0·38 | 0·06 | 5·81 |
| 0·66 | 0·50 | 0·04 | 5·66 |
| 0·68 | 0·67 | 0·025 | 5·44 |
| 0·71 | 1·00 | 0·007 | 5·03 |




**5** *Phase diagram for* $CaO+Al_2O_3$.[2,3] *Broken lines show liquidus to be expected if equilibrium could be attained between melt and lime, and melt and alumina*

where $C_S$ is the sulphide capacity, 32 is the atomic weight of sulphur, and $N$ is the number of g moles ($CaO+Al_2O_3+CaS$) in 100 g slag. Along any horizontal composition line in Fig.2*b*, $N$ is nearly constant, so that $a_{CaO}/\gamma_{CaS}$ must be constant, if $C_S$ is constant. Since $a_{CaO}$ must almost certainly decrease along such a composition line, it follows that $\gamma_{CaS}$ also decreases. But the change, as $N_{CaS}$ rises from 0 to 0·04, is not likely to be great.

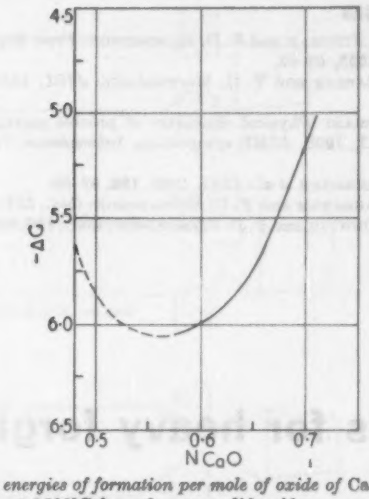
In view of these considerations, it is probably wisest to take the lime activity as dependent only on the ratio of CaO to $Al_2O_3$. The lime activities calculated in this way are shown by the full line in Fig.4.* The values of $(p_{O_2}/p_{S_2})^{\frac{1}{2}}$ at saturation are probably accurate to $\pm 5\%$; if $K$ is taken as accurate to $\pm 5\%$, and the assumption concerning the constancy of $a_{CaO}$ at constant proportions of lime to alumina is correct to $\pm 5\%$, the derived activities should be accurate to about $\pm 10\%$.

The lime+alumina phase diagram is shown in Fig.5; it is based on the work of Rankin and Wright,[11] as revised by Chipman[3] in the light of more recent studies of calcium aluminates. From this one can infer that were it not for the formation of crystalline $3CaO.Al_2O_3$, saturation with lime would occur at 1500°C at a mole fraction of lime of 0·72±0·01. It can be seen from Fig.4 that the lime activity curve extrapolates satisfactorily to unity at about this composition.

The alumina activities can be calculated from the lime activities by application of the Gibbs–Duhem relationship, after the alumina activity has been derived for the melt saturated with $CaO.Al_2O_3$ at 1500°C. This is done as follows. From the heat of formation of $CaO.Al_2O_3$ measured by Coughlin[12] and the relevant heat capacities[13,14] one can calculate that at 1500°C, $\Delta G^\circ$ is $-12220\pm700$ cal for the pure phase reaction

$$CaO+Al_2O_3=CaO.Al_2O_3$$

* If the activities are calculated by the other method, the values for lime are lower than those shown in Fig.4 by amounts ranging from 4 to 10%; the values for alumina are correspondingly higher. This is what one would find if $\gamma_{CaS}$ at saturation were lower than at high dilution by this same small percentage. Since the activity of lime in a $CaO+Al_2O_3$ melt may fall slightly as CaS is added to it, the decrease in $\gamma_{CaS}$ may be slightly greater than this.




**6** *Free energies of formation per mole of oxide of* $CaO+Al_2O_3$ *melts at 1500°C from the pure solid oxides*

Thus in equilibrium with the crystalline aluminate, when $N_{CaO}$ is equal to 0·58, $a_{CaO}.a_{Al_2O_3}=3{\cdot}12\pm0{\cdot}7\times10^{-2}$. With $a_{CaO}$ equal to 0·21, $a_{Al_2O_3}$ equals $0{\cdot}15\pm0{\cdot}03$. The phase diagram indicates that were it not for the formation of crystalline aluminates, the melt would become saturated with alumina at a mole fraction of 0·5 (±about 0·02). The alumina activity thus rises to unity at about this concentration, from the value of 0·19 when $N_{CaO}$ is 0·58. The lime activity must therefore fall simultaneously from its value of 0·21 to about 0·04 at alumina saturation. In the light of the lime activity values, the best compromise seems to be to set this saturation limit at 0·48 for $N_{CaO}$. The alumina activities for melts in which $N_{Al_2O_3}$ is less than 0·42 have been derived from the value at 0·42 and the measured lime activities. They can be checked at two points as follows. From the available free energy data[12–14] on $3CaO.Al_2O_3$, one can calculate that when the melt is in equilibrium with this crystalline solid at 1500°C, i.e. when $N_{CaO}=0{\cdot}70$

$$a^3_{CaO}.a_{Al_2O_3}=1{\cdot}18\pm0{\cdot}63\times10^{-3}$$

The alumina activity calculated from $a_{CaO}$ with this equation, is $0{\cdot}016\pm0{\cdot}009$, compared with 0·010 derived from the Gibbs–Duhem equation. When the melt has the composition $12CaO.7Al_2O_3$ ($N_{CaO}=0{\cdot}63$) one can calculate from free energy data[12–14] and an estimated entropy of fusion of 5·0 cal deg.$^{-1}$, per mole of oxide that

$$a_{CaO}.a_{Al_2O_3}{}^{7/12}=0{\cdot}070\pm0{\cdot}024$$

The alumina activity calculated from $a_{CaO}$ with this equation is $0{\cdot}068\pm0{\cdot}024$ compared with 0·070 by the Gibbs–Duhem calculation. The agreement is satisfactory.

Figure 6 shows the molar free energies of formation of $CaO+Al_2O_3$ melts at 1500°C from crystalline lime and alumina. A summary of the numerical data is given in Table II.

**ACKNOWLEDGMENT**

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**REFERENCES**

1. C. J. B. FINCHAM and F. D. RICHARDSON: *Proc. Roy. Soc.*, 1954, **A233**, 40–62.
2. P. T. CARTER and T. G. MACFARLANE: *JISI*, 1957, **185**, 54–61.
3. J. CHIPMAN: 'Physical chemistry of process metallurgy', 44; vol.I, 1959, AIME symposium, Interscience Publishers.
4. K. P. ABRAHAM *et al.*: *JISI*, 1960, **196**, 82–89.
5. K. P. ABRAHAM and F. D. RICHARDSON: *ibid.*, 313–317.
6. E. W. DEWING and F. D. RICHARDSON: *ibid.*, **194**, 446–450.
7. T. ROSENQVIST: *Trans. AIME*, 1951, **191**, 535–540.
8. 'Selected values of chemical thermodynamic properties'; 1952, circular 500, US Bureau of Standards (I).
9. F. D. RICHARDSON and J. H. E. JEFFES: *JISI*, 1952, **171**, 165–175.
10. J. TAYLOR and J. J. STOBO: *ibid.*, 1954, **178**, 360–367.
11. G. A. RANKIN and F. E. WRIGHT: *Amer. J. Sci.*, 1915 (4), **39**, 1–79.
12. J. P. COUGHLIN: *J. Am. C. S.*, 1956, **78**, 5479–5482.
13. E. G. KING: *J. Phys. Chem.*, 1955, **59**, 218–219.
14. K. R. BONNICKSEN: *ibid.*, 1955, **59**, 220–221.

# Tools for heavy forging work

*R. C. Benson and R. J. H. Hunt*

**SYNOPSIS**

*Great efforts are being made to speed up forging operations by increasing the speed of presses and of handling. Improvements in design and use of the actual press tools can give almost comparable savings at greatly reduced cost; this paper suggests some ways in which this can be done. Special tools attached to the press enable speedier forging methods to be used for round bar forging, becking, spreading, closing-in, profiling, veeing, and cutting large sections. Loose tools such as porter bars, bolsters, becking bars, and mandrels for hollow forging also provide an opportunity of increasing production by improved design and maintenance, while even the smallest hand tools need the same attention, as failure to give this may nullify the effect of improvements in the larger tools.* 1985

## INTRODUCTION

MUCH ATTENTION is being given to the operational speed of forging presses, and nearly as much to the speed of handling. Improvements in these particulars can be nullified by inefficient tool design or process planning; in some cases improvements in the design and use of tools can give an increase in efficiency as great as that produced by drastic speeding-up of the press itself, and can achieve this with a much smaller capital expenditure.

The subject has been divided for convenience into two sections, namely (to use the terms found in the old accountants' inventories), fast tools, that is, tools attached to the press, and loose tools.

## TOOLS ATTACHED TO THE PRESS

Fast tools are those attached to the press, the supporting tools for becking, i.e. ring forging, and sundry other special tools. Types discussed are flat, swage, and V-tools, tools for spreading, necking, expanding (i.e. becking), closing, upsetting, and bending; also methods of holding and changing tools are discussed.

The tools in a press (or hammer) are sometimes called pallet and anvil to distinguish top and bottom blocks, or sometimes they are merely described as top and bottom tools. The simplest form that these can have is that of flat rectangular blocks, but much more elaborate shapes have been developed, and these will be dealt with in turn.

### Flat tools

Flat tools warrant no particular description, but an important point in their design, in common with most forging tools, is the contour of the edges of the working face.

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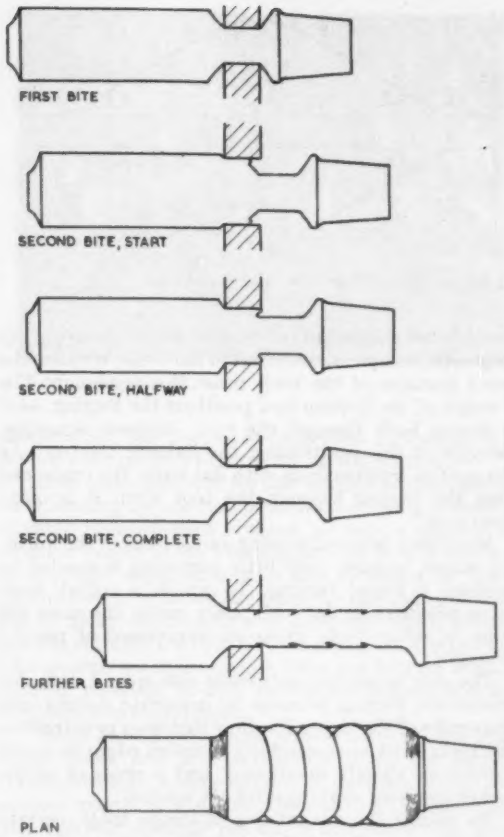
*Streamline edges of tools*

Forging tools should have well-rounded edges because if the edges are sharp, the impressions made by the tools also have sharp edges, and these sharp corners in the impression can very easily cause overlaps, as shown in Fig.1, when the next bite is forged down. This tendency can be removed by having a suitable rounding-off or fillet at the edge (Fig.2). In general it may be said that the deeper the squeeze the greater the rounding-off required.

The effect of these rounded edges, particularly in swage tools, is that the metal displaced by forging flows out through a trumpet-shaped, instead of a sharp-edged, orifice. As this orifice is made to contract by the tools approaching one another, the material is abraded from the surface of the tools at points *A*, and flows by cold-working to points *B* (*see* Fig.3).

Some years ago it was observed by the authors that when new tools were used with rather small rounding on the edges, and heavy squeezes, a saw-toothed effect was produced on the bar even when there was no actual overlapping; worn tools did not produce this




**1** *Effect of forging using tools with sharp edges*

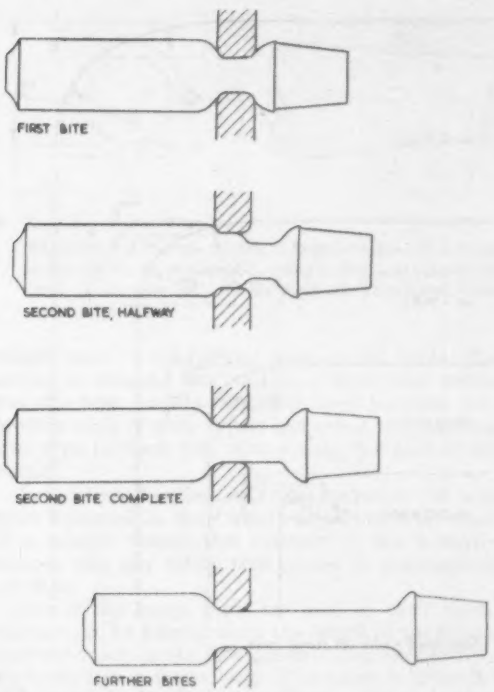
effect. It was decided, therefore, to produce a tool with side-rounding like that found on worn tools; this rounding is termed streamline radius, because it obviously conforms to the flow of metal round the tool. In order that the shape could be produced from a drawing, an approximation of the actual shape of worn tools was taken. Figure 4 shows a series of such approximations that are actually used in machining the edges of the tools.

### Swage tools

Round forgings can be made with flat tools that are, as mentioned, merely rectangular blocks with rounded edges. The well-known forging sequence, inherited from the blacksmith's anvil work, is to forge in turn square, octagonal, 16-sided, and finally a rough round with a series of small flats round the circumference. In hammer forging these flats can be removed by hand swages, and this is also done in light-press work. For heavier press forging, such swages become too heavy, and fixed swage tools fastened to the press are used. If such swages are suitably designed it is possible to do the whole forging operation with them, and they are in fact the best tools for speedy production of long-round forgings.

*Principles of design of swage tools*

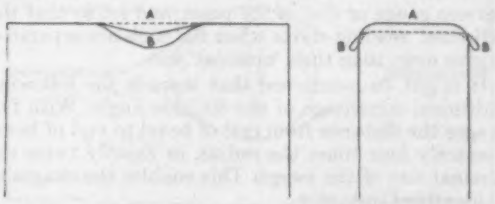
Swage tools, to do roughing down as well as rounding



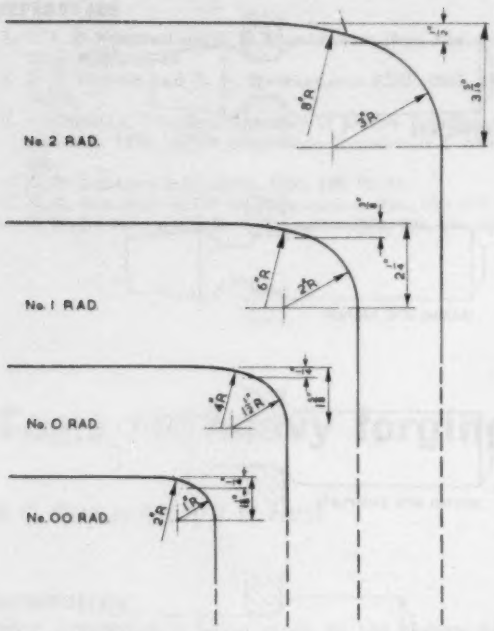

**2** *Effect of forging using tools with rounded edges*

up, consist essentially of a V-portion for the roughing and a curved part for rounding up.

In Fig.5 the curved part is shown with a radius $R$, and side bevels from $A$ to $B$ inclined at an angle $X$. In some forges swages are made with the separation across the diameter of the tools equal to $2R$ as in the figure; these are called 'full swages'. The smallest diameter that can be forged in such tools is $2R$. Thus, a pair of swages of 8in radius will meet with a separation of 16in and are called 16in swages in consequence. On the other hand, some forges use swages of different design which are less than full swages. For example, in such a series of tools the 16in swages which have an 8in radius might meet with a separation of only 12in. Such swages make an accurate forging 16in in dia., but can forge a smaller diameter than this with some loss of accuracy. This enables small parts of forgings to be reduced below 'nominal' size without changing tools. For example, if it were desired to forge a roll with a long body portion 16in in dia., with comparatively short ends of any smaller diameter down to 12in, the 16in dia. portion would be forged under the best possible conditions, and the more difficult condition of




**3** *Flow of material when using round-edged tools*



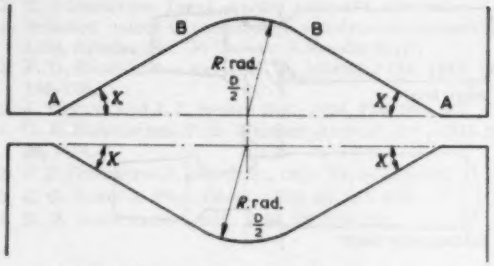

4 *Standard radii on forge tools*

forging in a swage really too big for the job would be accepted on the short ends because it would save the necessity of changing tools.

If the flat faces are cut back to make the tools meet with a distance between them less than $D$, an accurate round cannot be produced, because the forging cannot be kept exactly in the centre. It has also been found that the side angle $X$ cannot be varied greatly from 30°. If it is much less, too much time is required to smooth off the slight corners left after forging down along two axes at right angles. If the side angle is more than 30° the range of size that can be forged down to diameter $D$ is seriously reduced. The largest size which the swages will take is something over $2D$, round, square, or octagonal. When round forgings which are larger in diameter than the nominal size of the swages are being made in swage tools, the finishing to size is actually done by the side bevels and not by the curved portion of the swage. The angle to the horizontal of these side bevels has been standardized for many years at 30°. Forgemen have a rough rule that for every inch increase in diameter the press lift needed is 1¼in. This is incorrect; the actual figure is 1·153in. The ideal course, if swages are being used, is undoubtedly to have a special rule, something like the contraction rule used in foundry work, with this correction made to it, which can then be attached to the size gauge or dial of the press, and set so that the 'adjusted' reading starts when the tools are separated to give more than their 'nominal' size.

It might be mentioned that there is the following additional advantage of the 30° side angle. With full swages the distance from end of bevel to end of bevel is exactly four times the radius, or exactly twice the nominal size of the swage. This enables the swages to be identified instantly.

The speed of forging in swage tools is due partly to




5 *Standardized swage tools. Nominal size D*

the reduced amount of side spread, called 'bellying' by forgemen, compared with that in flat tools, because the bevel portions of the tools resist this tendency. The V-shape of the bottom tool positions the forging, as it is drawn back through the tool, between squeezes. Because of this positioning, the balance need not be changed so frequently as with flat tools; the crane can drag the forging through the tool when it is quite 'heavy on'.

Much time is saved in using swage tools in the finishing stages because very little cornering is needed to produce a round forging. To watch a round shaft being produced in flat tools, after seeing the same job done in swage tools, gives an impression of painful slowness.

The side bevels not only resist side spread, but also enable the forging pressure to penetrate deeply into the centre of the ingot. To allow this deep penetration, the tools must have carefully rounded edges to avoid galling, as already mentioned, and a press of ample power and long working stroke is needed.

To obtain the advantages of swage tools, certain limitations must be accepted. The range of sizes covered by one pair of swages is quite limited; to provide a full set of swage tools for a medium press, doing general work, six or eight different pairs will be needed.

The other point is that swage tools are quite unsuitable for use with normal hand tools such as V-sets, cutters, marking bars, gauges, etc. To carry out all the operations using these tools, the top swage must be changed for a flat block, and unless tool changing can be done quickly, much of the saving provided by these valuable swage tools will be lost.

It is in the direction of tool holding and tool changing, rather than in the actual design of swage tools, that recent development has taken place; a great deal more is still required.

*Swage tools for smaller work*

Heavy forges doing a large amount of round and fairly simple forgings can make effective use of swage tools. Smaller forges, engaged on more varied work, have generally been forced to accept the less efficient flat tools for their general round work. Use of special swages for making axles in quantities is, however, a well-established practice: as is indicated by Fig.6, which shows a water hammer, now an ancient monument, equipped with swage tools for making wrought-iron railway axles.

V-*tools*

V-tools, shown in Fig.7, should on no account be confused with swage tools. The V-tool arrangement is

6 *Old water hammer*

essentially a flat top tool and a bottom tool which is of a true V-shape with little or no curved portion.

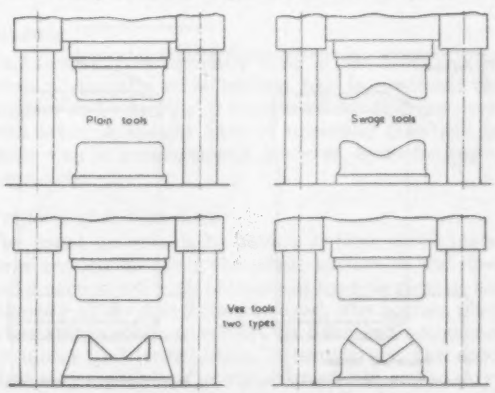
These tools are used for the forging process known as 'rounding up'. In this process the forging is rotated slightly between each squeeze, so that a part of it, equal in length to the width of the tool face, is reduced to a rough round of smaller size as shown in Fig.8. This differs fundamentally from the method used with flat or swage tools of forging along the ingot. V-tools are not suitable for this; if it is attempted, the flat top tool penetrates more deeply than the bottom V-tool, causing bending. In fact V-tools are not suitable for anything but round work.

V-tools have a very much greater range of size than swage tools, and are particularly useful for forging round jobs with a large number of changes in size over a short length. A V-set can be used to form each step, and the end discards cut off, which cannot be done satisfactorily with swage tools. Positioning is provided by the shape of the bottom tool, as with swage tools. The opening at the bottom of the V-tool allows scale, which falls off the forging when it is squeezed, to drop clear and not become embedded in the surface of the job.

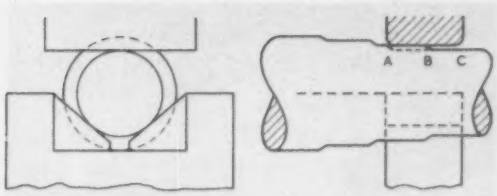
V-tools are often used for hollow forging on a mandrel. Mandrels and extractors are dealt with under the heading 'loose tools'.

*Alternative use of swage and V-tools*

V-tools, like swage tools, are not a new development, but in the past some forges used them to do all their




7 *Plain, swage, and V-tools*



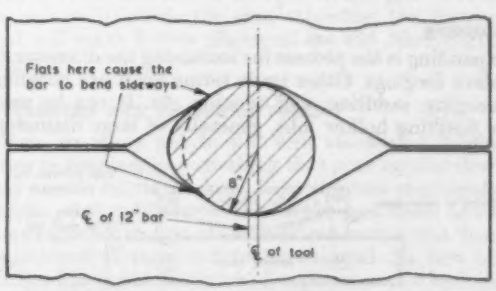

8 *Rounding-up in V-tools*
*The portion AB of the forging is forged down until it is equal in diameter to the portion BC, using a 'bite' less than the total width of the tools AC. As the final size is reached, contact occurs from A to C*

round work, while others used swage tools. Each school of thought was convinced that their method was the best. Ideally one must keep an open mind, provide tools of both types, and select the most suitable type for each job, thus getting the best of both worlds.

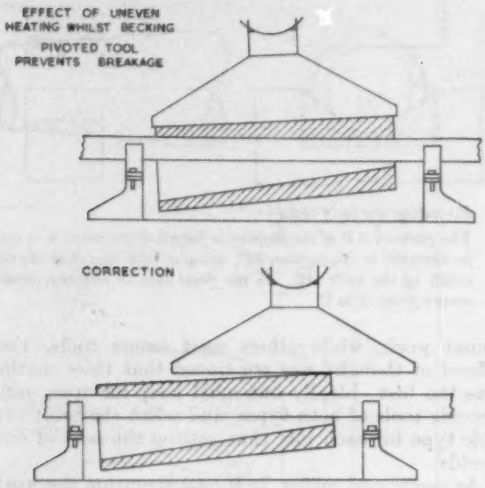
As mentioned earlier, in V-tool operation the workpiece is rotated in the V until one part of it is reduced to a smaller round; this rotation of the workpiece ensures that any droop that occurs is automatically rectified.

Now if the swage tools are used in their normal manner, i.e. by forging along the length of the forging, then the droop on the free side becomes cumulative as the workpiece is drawn back. This makes it difficult to keep the forging in the centre of the tools as it is drawn back, and if the bar is not centred, the bend is accentuated. Therefore it is easier to make a straight round bar in V-tools than in swage tools. If an attempt is made to forge in swage tools in the same manner as in V-tools, i.e. by rotational forging, then one runs up against another difficulty. Because the side angle of swage tools is less than that of V-tools (30° compared with about 40–45°), the workpiece tends to climb up the inclined sides as rotation proceeds and unless it is physically man-handled into the centre again, a banana-shaped cross-section will result, as shown in Fig.9.

Against this factor in favour of V-tools must be set the greater speed of working with swage tools when used for forging longitudinally. With V-tools, or swage tools if used in rotational forging, it is necessary to wait until the squeeze is finished before the workpiece is lifted and turned. In longitudinal working with swages, the crane can be moved while the press is actually squeezing so that the burden chain is deflected from the vertical position. Thus, as the press lifts, the forging slides along to the next position and




9 *Effect of squeezing-out of centre*




**10** *Expanding or becking*

during the next squeeze the crane again moves to repeat the process. Special tools are used for some forging processes and it has been thought most convenient to consider these under the processes that require them.

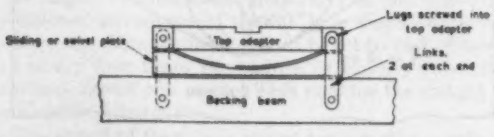
### Spreading and necking

To increase the width of a forging by reducing the thickness with as little elongation as possible, tools are required that have specially long, narrow faces, the long dimension being parallel to the axis of the ingot, and the short dimension across the ingot. For small forgings it is possible to use hand-tools to provide the spreading action, and the normal flat blocks need not be changed. In this application the spreading tools or sets, with their narrow faces, are held in place from the end of the job. This is not practicable for long or heavy forgings, and suitable top and bottom blocks are needed which have to be attached to the press in place of the normal forging tools.

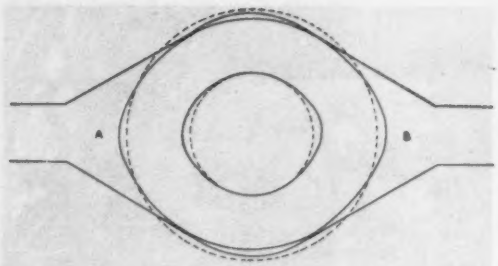
Narrow tools are used to forge out narrow necks between parts of larger diameter. For larger work these, like the spreading sets, must be special top and bottom blocks; hand-tools applied between the flat tools become too cumbersome for the larger sizes. In the past, the practice has been to use narrow flat tools, but for forging out narrow necks on round jobs, a bottom V-tool, narrow like the top tools, gives greater speed and accuracy.

### Expanding

Expanding is the process for increasing the diameter of hollow forgings. Other trade terms for it are becking, enlarging, saddling, and opening out. It can be used for finishing hollow jobs, generally of large diameter,




**11** *Built-up expanding tools*



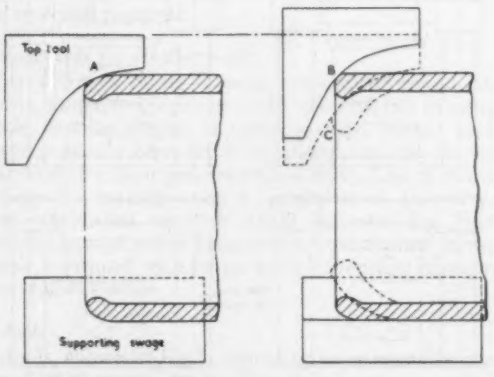

**12** *Process of closing-in*

or to increase the size of hole, ready for hollow forging on a mandrel. For expanding, a top tool, similar to that used for spreading, is required. In place of the bottom tool, the top part of the forging rests on the expanding bar, which is passed through the hole in the forging, and rests on supports at each end beyond the forging, as shown in Fig.10. The top portion of the hollow forging is made thinner when pressure is applied, and when the bar is rotated, another part of the circumference is similarly thinned, so that ultimately the wall thickness is reduced and the periphery proportionately increased.

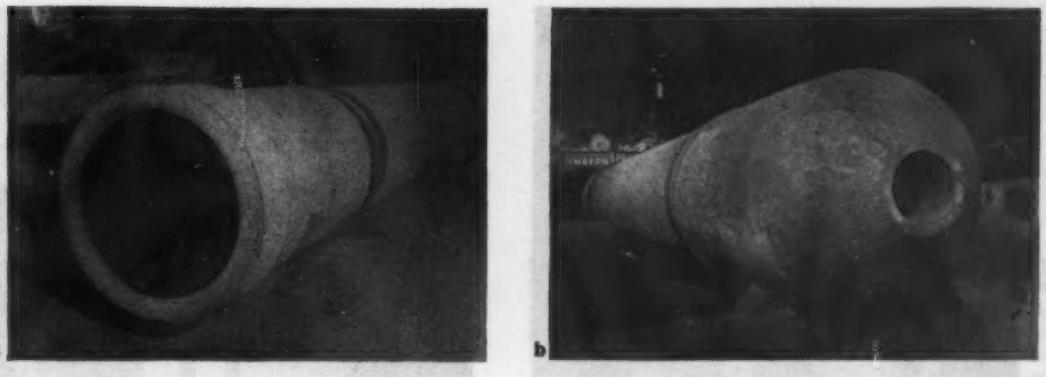
When comparatively long drum-forgings are made by expanding, uneven heating may cause trouble by making one end of the drum expand more than the other. If the top tool is rigidly attached to the crosshead of the press, it may be unduly strained, and it is a good practice to provide a small swivelling adjustment in the tool, as shown in Fig.10.

The tool need not be a large one-piece tool, as shown in Fig.10, and in fact it is better to use a built-up tool as shown in Fig.11. In effect this is merely a bar hanging on four links with a swivel plate sliding along its top face to allow the bar to pivot. The separation of these parts is sufficient to allow the heat from the forging to dissipate and avoids the heat stresses that are usually the cause of failure with deep sections. If the bar does break it is a comparatively cheap and easy item to replace.

A further modification has been found possible when forging rings of large diameter. It is normal practice to provide a tool with a long face, parallel to the centre line of the job, but for large rings a flat and quite thin plate can be used, which merely covers the face of the




**13** *Closing-in boiler drums*



**14** *Boiler drum* (a) *before and* (b) *after closing-in*

crosshead, and gives extra head-room. The plate cannot support the forging pressure, so it must not extend beyond the crosshead; therefore, the greatest width of ring that can be made in this way is limited in practice to the width of the crosshead of the press.

#### Closing-in

Closing-in is a special process, related to hollow forging. In its simplest form it consists of squeezing a hollow forging between swage tools, as shown in Fig.12, so that the vertical diameter is reduced and the material in the wall thickness is compressed at *A* and *B*. The tube is then rotated slightly and squeezed again, so that ultimately the diameter is reduced, both inside and out. Very little thickening of the wall takes place, most of the material displaced at *A* and *B* flowing longitudinally, so as to increase the length of the tube.

The swages used for closing should be so proportioned that each of them has two-point contact with the tube, and the top swage should be free to slide laterally, so that the two-point contact is maintained when the tube has been made oval by squeezing, and is then slightly rotated. When closing a 40in dia. tube a side displacement of about 2in is needed. The closing-in of the ends of forged steel boiler drums is a variation of the process, in which the bottom swage tool merely supports the parallel drum, and the top swage tool is tapered or curved longitudinally to the required profile, as shown in Fig.13. A boiler drum before and after closing is shown in Fig.14.

#### Upsetting

This operation is normally done in flat tools though often a specially wide bottom tool is required; the bolsters and other loose tools used for this are dealt with later. A special form of upsetting that will be dealt with in greater detail, however, is the forging of large discs.

*Profiling of turbine discs*

The usual practice is to have a bottom anvil plate, large enough to cover the whole surface of the disc, and a narrow top tool, of length at least as great as the diameter of the disc to be produced. The bottom plate is sometimes made to revolve by hand and sometimes by motor and worm drive. Alternatively, the anvil plate may merely rest on the sliding table, and so carry the job into and out of the press, while the top tool is hung on a ball-bearing spindle, and can be rotated manually by the press gang.

Of these methods, the hand rotation of top or bottom tool is preferable; it can be set in motion as the press lifts, and stopped with a jerk, by the press dropping on to the job. In this way a higher rate of pressing is obtainable than with any other forging process. With a power-driven anvil it has been found disastrous to try to drive the press at full speed unless a very efficient cushioning and slipping device is incorporated in the drive. The chief objections to either method are that edging up is impossible and that very high pressures are required because of the large area in contact with the anvil.

To produce discs bossed on the bottom surface, circular recesses are needed in the anvil plate, while bosses on the top surface are obtained by separating movable shoes that slide on the surface of the top tool.

*New method of profiling discs*

Figure 15 shows a turbine disc forged to profile by a method recently developed. Removable top and bottom profile plates are attached to top and bottom tools with faces of normal proportions. To rotate the discs between squeezes a pivoted beam is used, swinging in a slot through the top tool as shown in Fig.16. A manipulator is desirable to place the disc in position, and its arms can be used to push the disc around, so relieving the gang of manual labour. The beam-dogs drop free when the disc is in position for forging, and are swung back, ready for another rotating movement, after squeezing and lifting.

The new method is specially valuable for discs with wide rims, but while it is possible to forge out a deep groove round the boss, the depth of this groove must be reduced towards the rim, otherwise the forming tool will make hollow places on the rim itself during forging.

### ATTACHING AND CHANGING TOOLS

There are many people who still visualize a forging press or hammer as something that goes up and down and carries on its working faces the two rectangular blocks previously mentioned. In the past these blocks were regarded as part of the machine, and it was 'front page news' if they had to be changed. In fact one author has in his lifetime had experience of a hammer tool which was actually shrunk on to the piston rod.

**15** *Turbine disc forged to profile*

**16** *Method of profiling discs*

The commonest attachment of the tools to the press or hammer is probably still by means of a dovetail, glut, and taper key. This type of tool and method of attachment goes back to the very early days of forging. The old water hammer shown in Fig.6 also had this dovetail method of attachment.

If one considers the following summary of the tools which have been described one can see how this idea of permanent attachment has to be modified if use is to be made of such a variety of tools. These are: flat tools, normal; flat tools, wide; flat tools, narrow (several pairs); swage tools (perhaps six pairs); V-tools to go with narrow necking tools; expanding tools; spreading tools; closing tools; rotating tools for profiling discs; fixed V-setting and cutting tools (if used).

It will be seen that there can be well over 20 different sets of tools. It is not likely that the whole 20 or so variations will all be required in one day, but five or six is quite common in a jobbing forge, and some of the changes would be made without returning the heat to the furnace if tool changing were quick enough.

Our need is for the quickest possible means both of changing tools and of holding them in the press, and we throw this out as a challenge to our engineering colleagues.

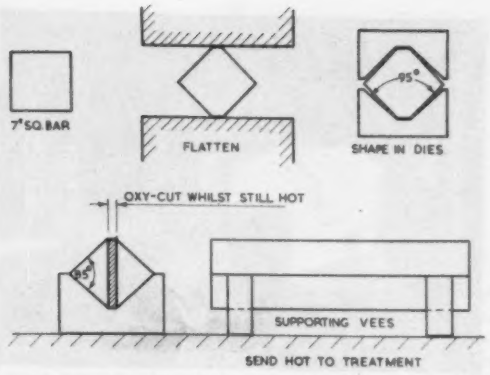
## LOOSE TOOLS

A large and quite expensive equipment of loose tools is needed to make heavy forgings. In the past, loose tools used for lighter forging were light likewise, and as with the tools used by a smith, generally made by a smith or by the forgeman himself. As forging work increased in size, the tools naturally did so too, and now the larger tools such as porter bars, mandrels, bolsters for upsetting and so on, are really items of plant; the cost of the largest of them runs into thousands of pounds and even the small hand tools can, in total, cost a great deal.

Starting with the smaller tools and working upwards in size, the inventory is surprisingly large. Among tools that can still be made in the blacksmith's shop are handling hooks, rakes, paddles for bricking up, and scaling chisels. All these can be made of welding quality steel except the scaling chisels; the heads of these last can be of high-carbon steel welded to mild steel handles and hardened. It is strongly urged that great attention be paid to the supply and maintenance of all these minor tools; too often the work of an expensive press, with its gang of men and its furnaces, can be held up for deficiencies in such tools, and this is the worst kind of false economy.

### Identification stamps

These are made by specialist firms and generally give little trouble. Usually a complete set of numbers and figures is kept in a box, and it is good practice to have each set examined weekly by a reliable man. If the stamps are made by a good supplier, the only attention needed is to grind off the mushrooming at the head of the stamp. It is most important that this should be done from the safety angle, and it also enables the stamps to be used until they have become so short they cannot be held, whereas, if neglected, large pieces tend to break off the top end. This may seem a small detail, but cases have been known of small forgings being made for government inspection where no less than 50 impressions (figures or letters) have to be made on one small article. There was, in one case, difficulty in finding enough room to put the




**17** *Method of making 6-in V-sets*

stamps on, and the time taken to stamp-up was almost as long as that to make the forging.

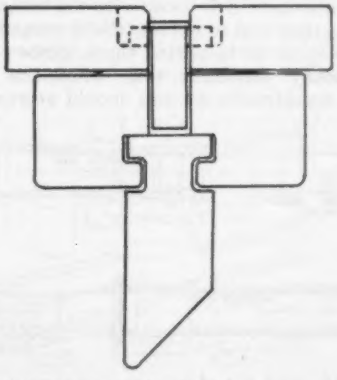
### Measuring tools

The lath or length rod, and the callipers are still the only ones used in most forges, though of course, for indications of diameters, the press travel indicator, or the peg (stopper) on the hammer, are themselves measurements of size. There is no doubt that less primitive methods will be evolved in future, and the optical machine may eventually be developed by BISRA so that it does all measuring in both directions.

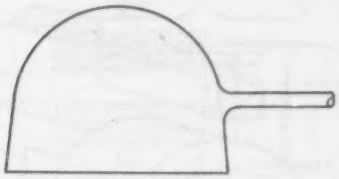
However, for measuring large diameters optically, it must not be forgotten that a ray of light cannot penetrate a re-entrant portion or hollow in the surface of a forging. Large forged slabs, for example, are often thicker at the edge than in the centre, and to measure the minimum thickness, which is the important thing, callipers are still needed. These callipers, as the work gets larger and larger, will definitely have to be mechanically supported, and not held in the hand. They should also, I think, close on to the forging under a light pressure and read the appropriate size on a dial in the same way as the pivoted beams that are used to measure the eccentricity in machined bores.

### Marking-bars and cutters

The next category is that of tools for marking, shaping, gouging, punching, and cutting. All these tools are pressed by the main forge blocks, and have to make



**18** *Special rotating tool for hand tools*



**19** *Cutter for use with swage tools*

some sort of impression on the heated workpiece. They must be reasonably hard, therefore, and able to resist rapid heating and cooling. Moreover, they are inevitably bent slightly during use, because of hollows in the tools caused by wear, so that a further necessity is the ability to withstand this slight bending without breaking. The usual material is Ni–Cr, or Ni–Cr–Mo steel, hardened and tempered as high as possible to give the maximum ductility consistent with hardness.

The most commonly used tool after the marking bar is the V-set. The section is sometimes triangular, with one 90° and two 45° corners. Sets made this shape are liable to fall over when pressed, if there is play in the crosshead, the more so if they have been distorted in use. Good practice is to make the larger angle of the V-set about 85° instead of 90°, the two smaller angles therefore being 47½° instead of 45°. One way of producing such a set is by oxy-cutting from a long-cornered square or diamond shape, as shown in Fig.17. Another successful method of producing correctly shaped sets is by casting (in spite of predictions that castings would be unsuitable), and one forge uses nothing else for sets from 4in up to 10in.

In the past it was the practice for forge men to make their own tools, including sets, and in some forges this still holds. The attitude is that if a man makes an ineffective tool, it is his own fault, but from the company's point of view, this is fatal.

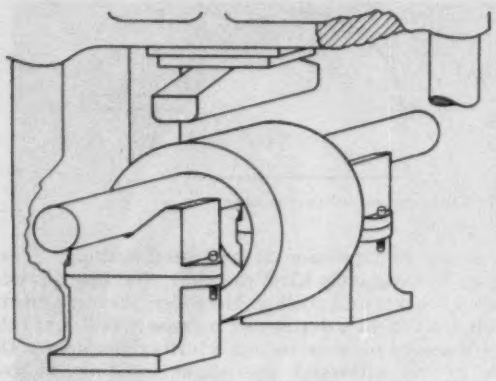
The important point about all hand tools is balance, and with castings this can be very easily arranged by either having a square hole in the end of the set or two round holes, the sets being picked up by the appropriate handles.

For very deep setting the sets are usually carried in a special rotating tool as shown in Fig.18.

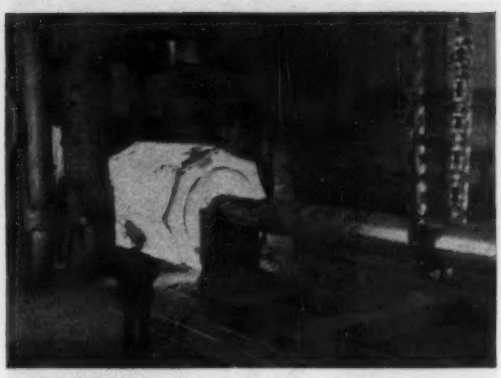
With cutting tools, balance is also very important. Very large flat cutters must have the handle exactly at the balance point so that after cutting as deeply as possible with the thin edge of the cutter, the cutter can be turned over and the thicker edge used for ensuring a cleaner cut.

Some forges use cutters with curved tops to fit in swage tools, as shown in Fig.19. This practice saves time, but the curved top must be correctly shaped for the particular swage in use, and the cutter well tapered from top to bottom so that the top face does not mark the top tool. Cases have also been known where swage cutters, driven too far through the job, have marked the bottom tool. As with other hand tools, an essential point is the question of balance: the part below the handle needs to be slightly heavier than the part above it.

The practice of hot cutting by oxy-torch will be dealt with later: it is hoped that this process may eventually do away with all other methods of hot cutting.



**20** *Expanding bar*



**22** *Built-up expanding bar*

#### Expanding bars

The expanding bar, as shown in Fig.20, is essentially a beam. When used for narrow rings, and starting with large holes, it may not be heavily stressed, but when starting with small holes, and expanding long tubes or billets the bar itself is sometimes stressed beyond the elastic limit. At every squeeze the bar is bent downwards (Fig.21), and the force to produce this bend makes an impression on the wall of the tube or billet. When the bar is rotated the bow is turned upwards and the force required to straighten it makes another impression in the wall of the forging.

This description of a brutal process shows why it is necessary to take great care in the material used for becking bars, and in their preheating before use and stress relieving after use.

If mild steel is used for the smaller becking bars, they can bend without making any reasonable impression in the forging, so some steel with a higher elastic limit is essential, and such steels are best used in the normalized and tempered condition. Even then, the bars should be regarded as expendable stores with a limited life.

#### Built-up expanding bars

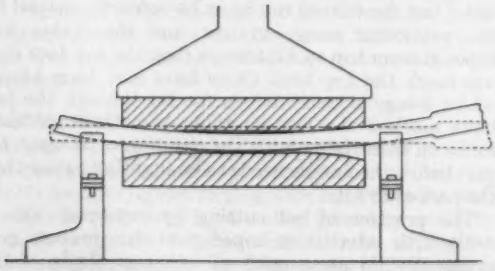
Any expanding bar must have some extension of its length beyond the working portion, to enable it to be passed through the forging and to be turned when in position. A good practice is to have bars of only slightly different sizes joined together, as shown in Fig.22. The smaller of the two should be the largest size that can just enter the hole in the billet, and the other perhaps 2in or 3in larger. This second bar is brought into use as soon as the hole has been opened out enough. Thus, the smaller bar, which is more severely stressed, is not subjected to either excessive working or heating. Despite such precautions, the life of the smaller bar is usually the shorter and it is then an advantage to replace the smaller bar only, fitting the replacement into a socket bored in the larger. A number of such pairs of bars are required; the larger sizes which are not severely stressed can be made of mild steel, and the milder it is the better.

Another point is that the first or smaller bar should be much longer than the billet, twice the length if possible, so that after forging for one or two revolutions with the billet on one part of the bar, it can be moved along so that a colder part comes into use. Paradoxical as it may sound, it appears to be the combination of sudden heating and cold working (overstressing) that causes becking bars to crack.

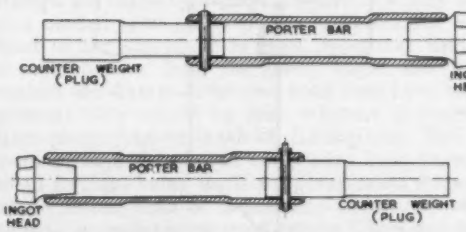
An interesting form of becking bar was a scrapped naval gun, complete with the rifling in the bore. This absolutely refused to clink after years and years of use. The only trouble was that where the joint between two of the shrunk-on tubes had been placed in the middle of the billet, the jacket which had covered and hidden the joint had to take the whole bending stress, and became bulged locally. It was possible in later use to put these joints where they were not subject to bending.

#### Porter bars

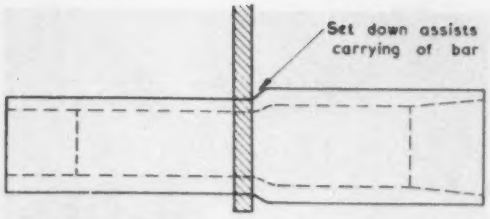
It is suggested that modern methods of handling now coming into use will do away with the balanced porter bar altogether, and so obviate the thousands of hours, in total, spent in balancing them. Since time represents money, especially time when the forging is cooling, considerable savings should accrue, but it is



**21** *Effect of becking using a small expanding bar*




**23** *Double-ended porter bar*




**24** *Balance of double-ended porter bar*

very difficult, if not impossible, to do away with porter bars in existing forges, and this ingenious and useful device will continue with us for very many years. Certainly a lot of porter bars in use are clumsy time wasters, but with better design and construction they can still give useful service. Forge folk are wonderful improvisers, but with a tool so essential and so important as a porter bar, what a tragedy it is that so often it is not actually designed around the job it has to do, but around the piece of material available to make it.

*Standard sizes of porter bar*

The conventional design is a tubular head design to fit the feeder head of the ingot. The heads, sometimes called chucks, used in the past were fitted with screws to attach them rigidly to the ingots and to cover variations in size of the feeder heads. Most forges have given up these screws because of the time and cost required to adjust and maintain them; instead a range of standard ingot heads is handled by a corresponding range of porter bars.

*Double-ended porter bars*

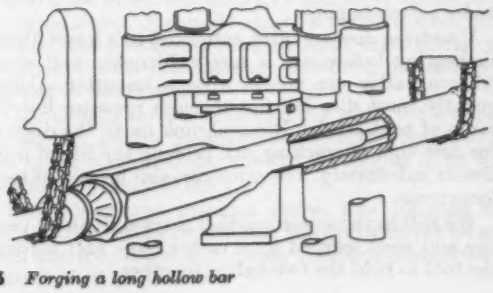
The body of the porter bar in the past was a solid bar of small diameter, fitted into the chuck at one end; and weights shaped like discs or short tubes were used at the other end to counterbalance the weight of the ingot. Much time was lost in putting on or moving these weights. A later development has been to make the whole porter bar one long tube, as shown in Fig.23. The two ends can then fit two sizes in the standard range instead of only one. A further advantage is that the burden chain can be applied at any position along the bar.

Extra balance weights, if needed, take the form of dummy ingot heads, usually termed plugs; these have to be changed from one end to the other if the bar is changed from one of its sizes to the other, and it has been found useful to drill both bar and plug to take a fixing pin to prevent the plug from moving.

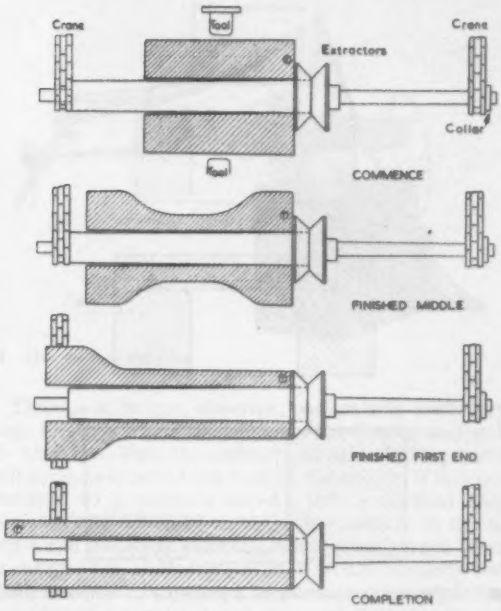
In some cases it is possible to make tubular porter bars long enough and heavy enough to balance the heaviest ingot used without extra balance weights. Many forges, however, are much too narrow to allow this and the movable plug has to be accepted because it gives a concentrated balancing load with less length.

Where a tubular bar, without extra weights, can be used, a point to watch in design is that, although the tube must be thick enough to carry the ingot, the outer diameter must not be so large that the bar will not go on the ingot. This inevitably means that the tube must be shaped and the authors suggest that the balance point of the empty porter bar should be on the smaller diameter adjacent to the set-down, as in Fig.24, so that the set-down helps to steady the bar when being carried. It also has the advantage of ensuring that no matter what ingot or forging is carried in the bar the balance never comes on the set-down.

The exterior of the bar should preferably be left as forged, but the ends should be machined inside with a rough cut to fit the ingot heads.

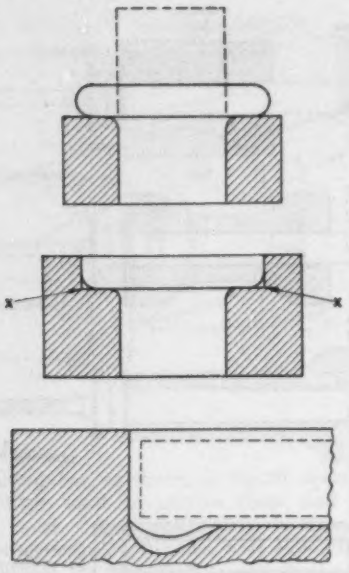


**25** *Forging a long hollow bar*




**26** *Stages in forging a long hollow bar*

**27** *A 76-ft hollow vessel forged on a 25-ft mandrel*



**28** *Difference in upsetting on a plain die as compared with a semi-closed die*

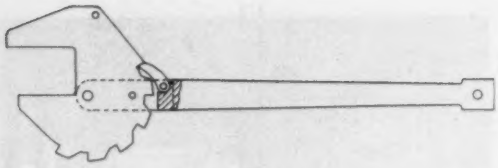
### Mandrels for hollow forging

The process of hollow forging on mandrels differs from the expanding process in that the forging is bedded on to a mandrel. Thus, the mandrel fixes the diameter of the hole, and only one size of hole can be produced with any given mandrel. On the other hand, there is little restriction as to the length of hollow forging which can be produced on a mandrel whereas, in expanding, the length is strictly limited. Figures 25 and 26 illustrate the various stages in forging a long hollow tube, and Fig.27 shows a 76-ft long hollow vessel forged on a mandrel only 25 ft long.

The mandrel has a taper, usually 1in dia., for every 100in length, but if both extractors and V-tools are used, this may be reduced to one in 150 or even one in 180. Handling extensions are desirable at both ends of the mandrel to enable the two cranes that are required for this work to be kept well apart. The extension at the small end should be large enough in diameter to provide a purchase for turning. The extension at the large or extractor end of the mandrel can be made stiff and short, and if this is done it can be lengthened by putting a porter bar on to it. The alternative is a long and slender end, and with the smaller mandrels this is sometimes used deliberately to provide resilience. When the press is working rapidly the extension acts as a spring, and in the event of an accidental overload it bends before the crane can be damaged. If this occurs it must be straightened to give balanced turning. With the larger mandrels, the extension piece is detachable and called the draw bar.

The collar on the end shown in Fig.26 is to enable the crane to stand down the shop and move the job rapidly without danger of the chain swinging off the end.

Mandrels of small diameter, in relation to the job which is being forged, must be bored for water cooling if work is not to be interrupted by overheating. The largest mandrels are themselves usually made as hollow forgings in order to save weight, but are not normally water-cooled. Handling ends are similar to those already mentioned and are inserted in the hollow forged bore of the mandrel. Hollow forging can be done in either V-tools or swage tools, as previously mentioned. If swage tools are used, some form of extractor is now generally used and is, in fact, almost essential.



**29** *Spanner for large angle twist*

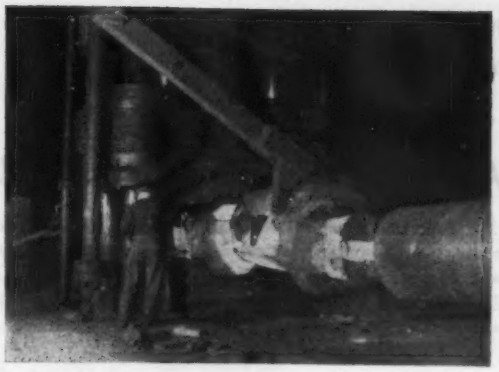
A simple type of extractor, introduced by one of the authors (R.C.B.), consists of two cones sliding on the mandrel. One cone is seated against a small collar at the large end of the mandrel, and the end of the tube that is being forged presses against the other cone as the tube lengthens. Further forging causes the tube to extend down the mandrel, that is, towards the small end, because the extractor prevents extension up the mandrel. This constant sliding down tends to keep the forging loose on the mandrel as forging proceeds. Without such an extractor, some of the extension, due to forging, goes up the mandrel, and this has a tightening effect. At the end of the heat, the two cones are squeezed between the press tools and so forced apart, thus withdrawing the mandrel from the tube.

### Dies

It is possible to make forgings in completely closed dies under an ordinary forging hammer or a forging press, but the dies must incorporate dowels or some similar matching device. This is not normally economic since forge furnaces are unsuitable, handling devices too clumsy, and pressure too great. A more interesting application is the semi-closed die. One side of the die is open and the job is pressed by an ordinary flat forging tool that bears on part of the face at a time, the die and job being moved between squeezes. In this way forgings can be shaped that would be quite beyond the range of a drop-hammer or mechanized forging press. Figure 28 illustrates how upsetting on a plain die gives a rounded edge, while upsetting in a semi-closed die gives a square edge. The corners of the die need to be undercut so as to give a sharp edge after machining. This is because the impact pressure under a press is not sufficient to fill the corners of the dies, as it would be under a drop-hammer.

Upsetting dies are often subjected to a lot of abuse. Preheating before use is rarely adequate and stress relieving after use almost always forgotten. Consequently most dies fail not through pressure but because of heat cracks. Rings shrunk on to the discs at the first sign of cracking will prolong the life of a die almost indefinitely. The same can also be said of most forge tools.

We still have tools in use that started to break years ago and were secured by a rather large bolt through the tool to hold the two halves together.



**30** *Spanner shown in Fig.29 in use*

**31** *Oxy-cutting machine*

#### Spanners

Although twisting machines are commonly used for making crankshafts nowadays, there are forgings that are either unsuitable or too large for this method and for which the conventional spanner is still used.

Spanners of this type have the jaw portion hinged in the arm, so that the arm is kept near the horizontal while the jaw portion twists through the large angles often required, twists up to 180° being sometimes needed. The head or jaw portion may be locked to the arm by a simple pin passing through various holes in the head, but the pin is highly stressed and an improvement is the use of a hinged pawl as shown in Fig.29. The pawl engages various teeth in the jaw and the load is taken by the back of the pawl and not by its hinge pin, thus giving a much stronger construction. Figure 30 shows such a spanner in use.

#### Oxy-cutting equipment

Oxy-cutting gear has now become an integral part of the equipment of heavy forges. Deseaming is used to remove small cracks which, in the past, would have been removed by the dangerous process of gouging under press or hammer, and this process also deals with the larger cracks that used to take months of machine time, planting or slotting after weeks of annealing and cooling.

The oxy-profiling machine, and in some cases the deseaming gun, can also be used for cutting-out and marking-out operations with a definite saving, as one man does at leisure what would otherwise occupy a forging press and its gang of men; moreover, he can do it more accurately.

Finally, separating forgings and cutting off discards is also done much more cheaply and more accurately by oxy-cutting. Figure 31 shows a machine designed for this. The prototype was evolved at the Darlington Forge, and such machines are becoming increasingly popular in heavy forges.

Oxy-cutting should be carried out while the forging is still hot, partly because this saves the preheating fuel in the torch and also enables the forging to go for treatment while still hot.

The trolley-type machine shown was designed to make this possible by keeping the operator far away from the job, while still giving complete mechanical control of all movements.

There is a danger, however, particularly with very large forgings where the centre of the forging may still be very hot, that the ordinary oxygen cutting torch will produce a large blow hole at the centre. If it is not essential to produce a smooth cut, a method that obviates this difficulty on large diameters is to use an oxy-torch merely to start the cut, and an oxygen lance to complete it. Diameters of 56–60in are regularly cut by this method. If neat cutting to size is necessary, then this should be carried out at a temperature in the region of 450°C and on alloy steel forgings can be safely done during the treatment cycle.

#### Chains and dogs

Nearly all movements of heavy forgings and tools are made by crane handling. Sling chains, therefore, can be regarded as essential loose tools; moreover, for handling tools, the provision and maintenance of suitable lifting pins is quite an important factor. Gripping or hook type dogs are an invaluable aid in handling forgings, but space does not permit further discussion of these items.

#### Burden chains

The forged burden chain is a most important item of equipment. The old, and perhaps even now the commonest practice, is to make these chains of links cut from plate with pins riveted into them, the whole assembly being regarded as consumable. Because it is not possible to lubricate such chains, their life, with heavy and continuous work, is not very long, while their cost nowadays runs into hundreds of pounds. It has been found to be much better to make these chains so that the whole assembly can be stripped down for examination and overhaul, and to drill the pins so that they can be lubricated by Tecalemit greasers.

If the links are provided with bushes and periodically stripped, their life becomes prolonged almost indefinitely; all that has to be renewed is the bushes, but the stripping for examination has to be done fairly frequently because it is found that under hot conditions of working the lubricating holes get filled with carbon deposit etc. Sometimes this deposit even has to be drilled out if the examination has been left too long.

There are many other small tools and gadgets used in heavy forges, but enough has been said about loose tools to show the importance of their provision and maintenance and explain that the total cost of them can be quite large in heavy forge work.

# Discussion at the Autumn General Meeting 1960

*The Autumn General Meeting of The Iron and Steel Institute was held on Tuesday and Wednesday, 29 and 30 November 1960 at Church House, Great Smith Street, London SW1. At the technical sessions on fluid flow, held on 30 November, the President (Mr W. F. Cartwright) was in the Chair. The papers presented have already been published in the* Journal. *Discussions at the first two sessions were published in the July issue, and the final two sessions are given below.*

## Discussion on fluid flow in furnaces and converters

### SESSION 3

This discussion was based on the following papers (dates of publication in the *Journal* are given in parentheses):

- **'The aerodynamics of open-hearth furnace regenerators'**, by *C. Hulse* (Sheffield University) (1960, **196**, Nov., 264–274)
- **'The effect of flow distribution on air preheat in the open-hearth furnace'**, by *J. Chapman* and *W. Montgomery* (Steel, Peech and Tozer) (1960, **196**, Sept., 15–28)
- **'Notes on gas-flow pattern through the regenerative chambers of open-hearth furnaces'**, by *L. G. Septier* (IRSID) (1961, **197**, March, 215–222).

Dr **N. P. Bacon** (Guest, Keen Iron and Steel Company, Ltd): Perhaps the most important feature of these papers is that they all reach the same conclusion. All the papers say that there is a considerable mal-distribution of gas flow in an OH furnace regenerator and that this leads to a reduction in the efficiency of the regenerator. These papers, together with previous work of a similar type,[1,2] provide sufficient documentation on this aspect of furnace design. Practical measures are now advisable if we consider the matter to be sufficiently important.

With the development of oxygen processes there are considerable increases in dust concentration; the effect that dust concentrations have on regenerators must be considered, and how far the type of treatment that the authors have described can be applied. How important is it to aim for another 50°C preheat or to get another fortnight's life out of the checkers? Which is the more important? These are typical problems.

Dr Hulse gave some temperatures obtained in checker packings during normal operation. He came to the conclusion that the temperature distribution confirms that the flow pattern of hot gases during operation is similar to that of cold gases measured during the course of 'full scale' model work. The temperature difference obtained was about 100°C across the packing. If the temperature difference had been 50° or 200°C Dr Hulse could still perhaps have reached the same conclusion. What I should like to know is whether or not he has any ideas about relating the temperature difference across the packing to the degree of mal-distribution in gas flow. I think Dr Hulse would agree that cold models tend to exaggerate such effects as mal-distribution while bouyancy effects which prevail in an operating regenerator tend to smooth out these effects.

Mr Montgomery and Mr Chapman mentioned the use of walls built above the bridge wall or above the checker packing. Could we have some indication as to the life of these additions? Do these baffle walls last for a really useful part of the campaign?

When an attempt is being made to improve flow distribution in a particular regenerator it is important that each case is examined individually. The idea of sloping the top and bottom of the packing is good in that it enables a greater heat exchange area to be built into the checker while at the same time it generally improves flow distribution. At Guest, Keen Iron and Steel Works we have carried out some model work to check the effect of sloping the top and bottom of the packing. For the particular case examined we found that a worse distribution was obtained when the top and bottom of the packing were sloped. Dividing the checker packing into thirds and starting from the bridgewall, 33⅓% down each third would be ideal. With the flat top we had 26, 32, and 42% respectively down the three sections. With a sloping top we had 16, 36, and 48% down the three sections. This effect arose because in this particular checker there was considerable recirculation over the top of the packing which was eliminated when the top of the checker was built up to give a sloping upper surface.

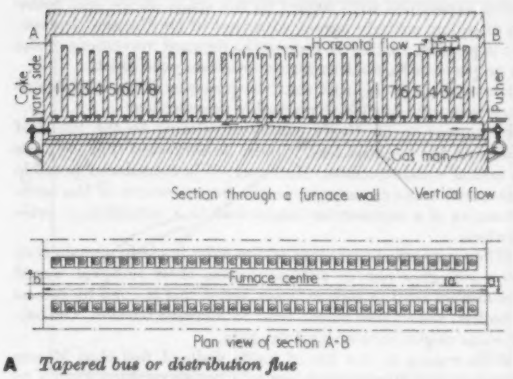
Mr **Montgomery**, in reply: In reply to Dr Bacon's question on the useful life of the various baffles, there were some constructional details that could only be determined in the light of operating experience. For instance, the baffles on the bridgewall were originally built 9in thick overall but the manner in which the waste gases flow from the slag pocket into the checker chamber caused undercutting at the baffle leading edge. This undercutting led to an early collapse with the bulk of the baffle material still capable of giving further service.

The undercutting was eliminated in later rebuilds by the inclusion of an 18in 'toe' at the base of the baffle leading edge. These bridgewall baffles can now be relied upon to last for 10–12 weeks before the first sign of collapse appears; by the end of a 14-week campaign they are perhaps 60–70% effective.

One point worthy of note is that in the diagrams (Figs.23–25) showing furnace performance, the group 'after inclusion of baffles' includes results from early trials when the various baffles, as then designed, gave effective service for only a few weeks.

The baffle walls on top of the checker filling were originally built freestanding, and partial collapse occurred in the furnace campaign. Now these walls are buttressed at four places on each side and can be relied upon to provide 100% service for 10–12 weeks before movement of the checker filling and general attrition cause gaps to appear along their length. At the end of a 14-week campaign the smaller baffle has all but disappeared while the larger is perhaps 50% effective. A surprisingly small amount of filling blockage occurs as the checker top baffles fail.

The splitter walls in the flues were originally 4½in thick for the whole of their 6 ft of height; no expansion allowance was




**A** *Tapered bus or distribution flue*

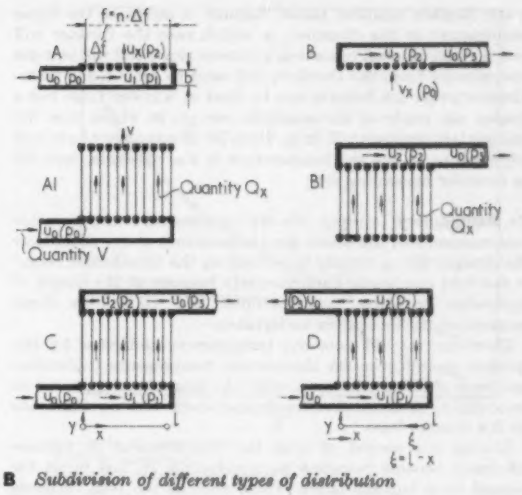
made along the length because one end was free. Experience has shown that these walls were unstable at 4½in thickness and the bends too steep for the free end to be of any value. Now these walls are 9in thick for the first 3 ft of height with two expansion gaps along the length.

A life of 3 or 4 campaigns is now expected from the splitter walls in the flues.

Mr **Chapman,** in reply: These baffle walls were intended for use on the conventional fuel fired OH furnace. If, however, oxygen is being used to assist combustion then an improvement in slag pocket design would be necessary to obtain maximum value from the bridgewall and checker top flow distributors.

Dr **M. Hansen:** I should like to give some fundamental explanation of the problem of manifolds that exists in the regenerators of OH furnaces. Both the practical operators and the scientists agree on the importance of air preheat in the operation of furnaces. Some years ago I noted that the scientific fundamentals were not thoroughly explored. I started with model tests, and I am very pleased that Dr Septier has quoted my tests and results. I feel, however, that one very important factor has not been mentioned in his paper and during discussion, and that is the relation of the cross-section of the flue and the free section in the regenerator checker work itself. For the up flow, also the cross-section below, the checker work is important. The result of model tests showed that this relation of the cross-sections should be as large as possible. This means the kinetic energy of the horizontal flowing gases should be low compared to the velocity in the regenerator checker works. I am fully aware that, with the existing low furnaces, there is often not enough space to realize this ideal relation of the cross-sections. Therefore I welcome the work of Dr Hulse and Messrs Chapman and Montgomery, because they have recommended other means of accomplishing a more ideal distribution. I am not quite sure if the proposal made by M. Septier can be realized in actual practice but it is a promising study. It is also important to improve the lateral distribution of the flow, and the second paper has indicated some ways of doing so. I agree with M. Septier that the advance history of the flow has also to be considered. That means that the approach of the flow through the slag pocket has first to be rectified before the distribution itself in the generator can be attacked. The distribution of the gases inside the slag pocket has been rather sadly neglected and I feel that this is one of the crucial points which should be attacked right away, in spite of its difficulty.

Dr **P. Veit:** There has been a very useful range of subjects: a practical examination by Dr Hulse on the actual flow distribution, proposals for practical improvement, and a theoretical paper. All agree that regenerators are unsatisfactory, and this is a challenge for every engineer, because we should not just limit ourselves to finding out that there is something wrong; we should set out to correct it.




**B** *Subdivision of different types of distribution*

I feel that other regenerators in industrial furnaces, and in particular, those of coke-ovens, are further advanced than those of OH furnaces. There have been many papers published by coke-oven builders. For instance, Fig.*A* of a tapered bus or distribution flue was proposed in a paper published in the year 1908 by Dr Still[3] as a means of improving the flow distribution in his coke-oven. One is unlikely to find a coke-oven operated at waste heat temperatures of 500° or 600°C. The aim is 150° or 180°C, and a point is attained where the danger of condensation of sulphur dioxide occurs.

The facts found by Dr Hulse are a complete confirmation of theoretical work carried out some 12 or 15 years ago. I may mention in this context the names of Professor Tollmien, Dr Reichardt[4], and Dr Hansen with the Max Planck Institute at Göttingen. They have found out, as I did with my problems over my thesis, that this problem has not yet been solved, despite some valuable work, by Mr George Davis[5] for instance, and they have started comprehensive theoretical work on the distribution. They have subdivided the different types of distribution as shown in Fig.*B*: there is the distribution A and A1, opposite it the group B and B1, and then the combination of these types with the ingoing flue, coming from the opposite direction (*C*) and from the same direction (*D*) as the collecting flue. They have found out and developed equations that govern this flow. The equations are complicated but they have been proved by model test. I spent several years in trying to find out how they work in actual practice, and the results which we discovered with Dr Hansen were very encouraging.[6] It seems that we really have the fundamental laws available. It is only a question of applying them. Dr Hulse's paper is a good proof of their validity. I suggest that these formulae be studied and utilized rather more in research laboratories and by research engineers.

There is one very important factor. As engineers we must ask ourselves, what do we gain by improving the distribution, and what do we have to pay for it? Every improvement of the distribution has its price, and the price is pressure loss. We should compare the lower fuel rate with the higher electricity consumption of our waste heat blowers. Only then can we really say if we make progress or not. In this connexion I have a practical question to put to Dr Hulse. Did he ever try to find out the pressure loss caused by these horizontal baffle plates, or have they only been tried out in the cold state? And what is their life?

Mr **A. W. D. Hills** (Imperial College): I wish to ask Mr Montgomery a question about the temperatures in his checkers. As I see it, the increase in preheat temperature of a furnace can improve its efficiency expressed in gallons of fuel per ton of steel melted, in two ways. Either it can make the heat transfer

in the furnace chamber faster, because it increases the flame temperature in the chamber, in which case the furnace will melt a given amount of steel in a shorter time, and the exit gas temperature from the checkers will tend to remain the same. Alternatively, the furnace can be fired at a lower rate, but a greater use made of the available energy, in which case the exit gas temperature will drop. Does Mr Montgomery have any information on the gas temperature in the checkers, and did he consider measuring it?

Mr **Montgomery,** in reply: We did consider suction pyrometer measurements of the waste gas temperatures above and below the checker filling, mainly as a check on the distribution found in the cold condition. Unfortunately because of the length of pyrometer required and cramped site conditions these measurements were never undertaken.

However, we did note the temperatures indicated by the furnace instruments for checker-top temperature (radiation) and base of filling (thermocouple). At most there appeared to be a slight fall in checker-top temperature with no difference on the checker base.

During the period of trial the improvement in furnace efficiency became manifest as a reduction in fuel input for normal shop top-tap times. Thus, each of the trial furnaces showed a lower average oil flow/h than that during previous campaigns but with a normal output rate.

## AUTHORS' REPLIES

Dr **Hulse** wrote, in reply: I should like to thank all who contributed to the discussion. In reply to Dr Bacon, it is certainly true that the temperature measurements made with bare thermocouples at the bottom of the checkers only indicate in a qualitative manner that the same type of mal-distribution is obtained in a working regenerator as was found in the cold trials. It was stated in the paper that bouyancy will tend to improve the distribution, and that the distribution found in the cold trials represents the worst possible condition that could occur in normal practice. However, experimental work by Rhydderch,* suggests that buoyancy is insufficient to nullify a tendency towards bad distribution.

Dr Bacon's experiences with a sloping top and bottom are most interesting. Theoretically, in the absence of friction, if the cross-sectional area of a duct with multiple offtakes is arranged to give constant velocity along its length, the distribution should be uniform. However, this is true only if the flow at the entrance to the system is regular: recirculation or the presence of eddies may completely alter the situation. This must be the explanation of Dr Bacon's experience.

* Department of Fuel Technology and Chemical Engineering, Sheffield University.

Our experience with regard to the space above and below the chequers entirely agrees with that of Dr Hansen. Indeed, if it is possible further to reduce the forward movement of the air or gas to zero, no distribution problem need exist.

However, it is thought that the presence of such baffles as have been used has led to negligible pressure loss.

In answer to Dr Veit's questions relating to the effect of baffles on the pressure loss, it must be confessed that we have no actual measurements. Moreover, it is considered possible that under some circumstances the improvement of the aerodynamics of a regenerator might lead to a reduction in pressure loss.

When unwanted turbulent eddies exist it seems certain that these will give rise to friction losses; their removal would presumably tend to reduce these, but if this is done by means of baffles, then these would tend to increase friction. On balance one might have a slight net gain.

With regard to the life of baffle walls, I feel that Messrs Chapman and Montgomery are in a better position than I to answer this question. I understand that it is satisfactory.

One last point on the *modus operandi* of baffle walls placed over the chequers. It is considered that they have a dual function. Since they partially obstruct the forward movement of the waste gases some gas is forced to take a downward path into the chequers. They also give rise to slow recirculation eddies in the region downstream immediately behind them and in this low-velocity region the waste gases also find it easier to turn downwards. They are accordingly capable of bringing about redistribution of the gases to a considerable area of the checker bricks.

M. **Septier** wrote in reply: With regard to Mr Hansen's contribution I should like it to be known that contrary to what he seems to think I have taken account 'of the relation of the cross-section of the flue and the free section in the regenerator checker work itself', which we would consider an equally important factor. My paper introduces this relationship by means of the coefficient $b$ defined in the appendix on p.220, and used in the formulae on pp.216–217 and 221.

## REFERENCES

1. J. E. DE GRAAF and G. W. VAN STEIN CALLENFELS: *Chal. et Ind*, 1953, Gr.IV/41, No.197, 1–8.
2. R. H. JONES and D. F. BRION: 'Gas flow in an open hearth model', 1958 Annual Meeting, AIME, New York City.
3. C. STILL: *Glückauf*, 1908, **44,** 961–969 and 993–1000.
4. H. REICHARDT and W. TOLLMIEN: *Mitt. Max-Planck Inst.*, 1952, **7.**
5. G. DAVIS: *Blast Furn. Steel Plant*, 1945, **33,** 568–578.
6. P. VEIT: *Arch. Eisenhüt.*, 1953, **24,** 93–103.

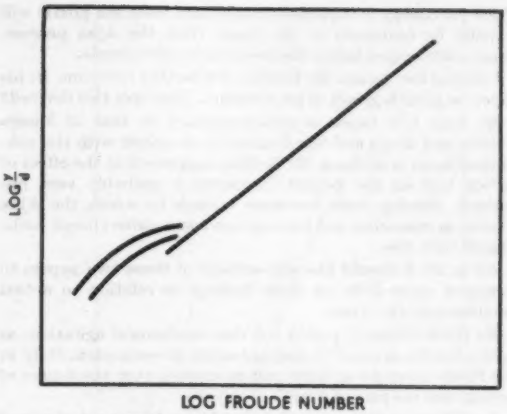
## SESSION 4

This discussion was based on the following papers (dates of publication in the *Journal* are given in parentheses):

- **'The dynamics of the blowing process'**, by *T. Kootz* (When this paper was presented a film was shown. August Thyssen-Hütte AG) (1960, **196,** Nov., 253–259).
- **'The physics of oxygen steelmaking'**, by *C. Holden* and *A. Hogg* (now with Salem-Brosius (England) Ltd) (1960, **196,** Nov., 318–332).
- **'The use of models for investigations of oxygen steelmaking processes'**, by *B. S. Holmes* and *M. W. Thring* (University of Sheffield) (1960, **196,** Nov., 259–261).
- **'A model study of splashing'**, by *Kun Li* (The United Steel Companies Ltd) (1960, **196,** Nov., 275–280).
- **'A model experiment to study the rate of gas evolution from the bath of an LD converter'**, by *J. M. van Langen* (Koninklijke Nederlandsche Hoogovens en Staalfabrieken NV) (1960, **196,** Nov., 262–264).

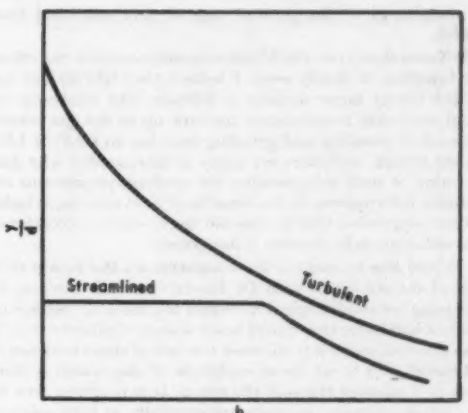
Mr **Holmes** presenting his paper, said: Since the paper was written, further work has been done to set up equations for the action of a gaseous jet upon a liquid surface. The apparatus being used is a large perspex bath with a lance (fed from a compressor via a flowmeter) playing on the surface. The height of the lance and the depth of the depression were measured by throwing a shadow image of the two on a graduated screen. The ratio depth of depression over tube dia. was plotted against Froude number. On a linear plot this appeared to be a parabola but on log paper (Fig.*C*) a marked deviation was noticed at low flow rates. On calculation of the Reynolds number of the jet it was found that the change in depth of depression corresponded to the change from streamlined to turbulent flow. It was interesting to note that in the region of transition, the depression was metastable, constantly changing from a deep narrow depression to a broad shallow one. The slope of the straight part of the curve is about 0·5°.

The effect of lance height was investigated and again there was seen to be a marked difference between streamlined and turbulent flow. The ratio depth of depression over tube dia. was plotted against tube height over tube dia. In the case of turbulent flow, the depth of depression decreased as the lance height increased in an almost exponential fashion (Fig.*D*). In




$y$ = depth of depression
$d$ = tube diameter

**C** *Plot of log* y/d *v. log Froude number*




$y$ = depth of depression
$d$ = tube diameter
$h$ = height of tube above liquid

**D** *Plot of* y/d *v.* h/d

the case of streamlined flow, as the lance was raised very little happened to the depression until the lance was relatively high off the surface, when the depression began to decrease as the lance was raised still further. This effect can only be observed with relatively small-bore tubes (using air as the gas), i.e. less than $\frac{1}{4}$in, because as the bore is increased the velocity required for the flow to be linear is so small that the jet momentum is too low to produce a measurable depression.

Two other variables which have been tested are the ratios tube dia. to characteristic bath dimension, and to depth of liquid in the bath. They have no effect provided the first is small and, in the second case, the liquid is deep enough to hold the depression.

The two variables left still to be tested are: ratio gas density to liquid density, and the angle of the jet to the liquid surface.

It is hoped subsequently to do an analysis of the splash being thrown up from the bath under various conditions. First, only the mass being thrown up will be measured, by catching it on weighed dry blotting paper and then reweighing after a known time of deposition. From the pattern of the splash, the direction at which it is thrown up can also be measured.

Dr **P. A. Young** (Head Wrightson and Co. Ltd): In the past there has been an undue emphasis on equilibrium and it is only in recent years that kinetic studies have made possible an understanding of the differences between the pneumatic and OH processes. It is to be hoped that some of our universities will pay increasing attention to this branch of metallurgy.

Thermodynamic considerations would lead one to expect the oxidation of carbon to CO to proceed preferentially to the oxidation of phosphorus to phosphate irons in a calcium-rich melt. Such considerations neglect the energetics of bubble formation; the work of Oelsen in this field is classical. He showed that in the absence of nucleating surfaces it was easy to build up 10 to 15 atm supersaturation with respect to carbon monoxide in a carbon–steel melt. The energy required to nucleate very small bubbles is large. If, however, bubbles are created by blowing through a melt, as in the basic Bessemer and Thomas processes, then surface is provided at which the carbon–oxygen reaction will proceed. Oelsen's work was carried out in smooth crucibles in the laboratory, but there is evidence of the same order of supersaturation (say 17 atm) in oxygen–steel processes, at least at the slag–metal interface.

If then, the carbon reaction is inhibited by surface energy considerations, what are the requirements which will enable the phosphorus reaction to proceed? The basicity, temperature, and oxygen potential of the slag must be such that there is a positive driving force for the phosphorus–oxidation reaction. For reactions to proceed at an adequate rate we must have a fluid slag, sufficient surface, and enough mixing to ensure that processes controlled by diffusion across the boundary layers are not impeded. Finally, if the carbon reaction is once nucleated the resulting boil is in some respects self-catalytic. These appear to me to be the bones of the problem, which is the relative rates of decarburization and dephosphorization in different steelmaking processes.

Dr Kootz examines the mode in which the lance, in a top-blown process, agitates the bath, and I agree in general with his conclusions. We have done some model work using a 1:12·5 model of the Consett converter. We can confirm the graphs given for the beginning of spraying with some accuracy. The onset of the phenomenon is sharp and readily observed. I am doubtful about the concept of deep penetration; this can certainly occur, but we have not found a clearly defined contrast between the two phenomena.

We scale our lance operation on momentum principles, i.e. we assume that, under any particular set of conditions, the fraction of jet momentum imparted to the fluids in the model and full-scale converter is the same, and the depth of the impression should be similar. We believe that the full-scale converter operates in the spraying rather than the deep penetration régime and the transfer of oxygen will take place variously between gas and metal and gas and slag, both directly and in droplet form, depending on the slag thickness, slag viscosity, lance height, and jet momentum.

Dr Kootz shows pressure distributions for a particular jet. We investigated distribution velocities for a large number of possible nozzles. The subject of lance design has been shrouded in mystery. A convergent–divergent nozzle of classical design, such as might be used by turbine designers to give maximum thrust, is not necessarily the best for oxygen steelmaking. Thus, a nozzle with convergence, followed by a parallel throat at the exit point, gives a more closely confined jet with higher velocities at longer distances from the lance. The rate of loss of momentum to the surrounding atmosphere is reduced. Thus, nozzle design can affect the mechanical movement of the slag, and it is also worth noting that the loss of momentum to a surrounding carbon monoxide-rich atmosphere will involve lower oxygen efficiencies, that a greater proportion of CO will be burned to $CO_2$, and that hence we may expect increased scrap smelting capacity, although we may also have increased lance wear.

I will add a practical point. At least one LD plant on start-up experienced a curious shift in metallurgical behaviour. It was found that the nozzle diffuser, machined to careful profiles, had worn back and changed the jet characteristics. Later nozzles were constructed to the worn shape and in this way jet stability was achieved. Thus, constancy and reproducibility of

the metallurgy of the process may dictate non-ideal nozzle profiles.

Dr Kootz shows two IRSID photographs in which the effect of lime injection is clearly seen. I believe that IRSID now use a parallel throat lance without a diffuser. The relatively long throat may help to accelerate the lime up to the gas velocity. The cost of crushing and grinding lime for an OLP or LDAC process is high, and there are many in this country who doubt the value of such an operation for medium-phosphorus iron. Accurate information on the benefits of lime blowing is lacking and the suggestion that it may aid the control of decarburization and dephosphorization is important.

I should like to make a few comments on the Kaldo at this stage. I do not agree with Dr Kootz that it is obvious that increasing rotational speed increases the metallic surface area which is laid bare. Our model work does not indicate this. The main effect of speed is to increase the rate of shear between slag and metal, and to set up an undertow of slag which is carried down and released through the metal. It is perfectly true that the carbon reaction proceeds preferentially at high rotational speeds but I do not think that the CO nucleation is brought about by quite such a simple mechanism as postulated in the papers. I should point out, however, that in model work it is easy to forget that fluid slags do not necessarily exist throughout the process. Thus, in a classical low-phosphorus LD practice the slag may remain 'dry' for a considerable part of the blow. Equally, in the Kaldo, if it is desired to make a low-carbon heat, a fluid slag may be deliberately avoided for part of the heat by using a high rotational speed at relatively low blowing rates.

In this way, the iron content of the 'slag' is kept down and the phosphorus reaction inhibited. Lining wear is at maximum with a fluid slag, which suggests another incentive to delay slag fluidity. When it is desired to arrest the carbon reaction the vessel is slowed down and the blowing rate may be increased. The slag melts out then with startling suddenness, the first indication being a distinct increase in rotating motor amperes. The slag is becoming sticky and it may be that it is carried on to the walls, thus increasing the moment of inertia of the vessel. The motor amperes then drop quite suddenly, perhaps to a mere 50% of the maximum, and the exit gas temperature drops with equal sharpness. The slag is now fluid and the phosphorus reaction has taken over from the carbon.

One historical point: it has been said that we should look more closely at this general problem of mechanical mixing and it may interest you to know that the first reference I have found to this concept is in Sir Lothian Bell's book.[1] Here we find a number of curves for the rates of decarburization and dephosphorization of iron in different refining processes. He appreciated the advantages which would accrue if phosphorus could be brought down simultaneously with carbon. He then devised a rotating vessel in which he placed his molten iron. He made a 'molten cinder' in a separate furnace, poured it into his vessel and rotated it. A graph shows the phorphorus coming down very rapidly and the carbon staying up.

The paper by Messrs Holden and Hogg, apart from being a very useful survey of overall principles, indicates some of the effort which has gone into the Ajax process. I should like to ask the authors to indicate how far the original ideas of Mr Albert Jackson and Mr Kemp were modified in the light of these laboratory studies.

It is interesting to see that they have studied the jetting of two-liquid systems. Has this a bearing on the Kaldo problem? Our studies suggest that under normal Kaldo operating conditions the slag layer is not penetrated by the jet and it would have been useful if the relevant data in the paper had been published quantitatively.

The emphasis on the stirring energy is interesting and I can confirm that on 100-ton Kaldos the energy requirement can approach 4 kWh/ton. The figure will vary according to the type of scrap charged, the state of the heat, and the viscosity of the slag. It is difficult to know in either LD or Kaldo processes what fraction of the total energy expended is transferred to the melt. With a strongly foaming LD slag presumably some part of the jet energy is imparted to the foam since the nozzle will actually be immersed in the foam. With the Ajax process, using a submerged lance, the problem is more simple.

I should like to ask Mr Holden one further question. In his paper he gives a graph of jet vitiation. How was this derived?

Mr Kun Li's paper is complementary to that of Messrs Holden and Hogg and the diminution in splash with the submerged lance is striking. Mr Holden suggests that the effect of carbon boil on the droplet formation is probably very important. Having been fortunate enough to watch the Ajax process in operation and having seen some quite violent boils, I agree with this.

All in all, I should like the authors of these two papers to comment more fully on their findings in relation to actual practice with the Ajax.

Mr Holden rightly points out that mechanical agitation, as in the Kaldo, appears to warrant more investigation. Only in the Kaldo have we an independent control over the degree of mixing and the rate of supply of oxygen.

I will here mention one of the problems facing a designer of a Kaldo vessel. The original Domnarvet installation has a nominal capacity of 26 tons. Its refining characteristics at about 28 rev/min are well understood. At what speed should a 100-ton vessel rotate to give equal refining times?

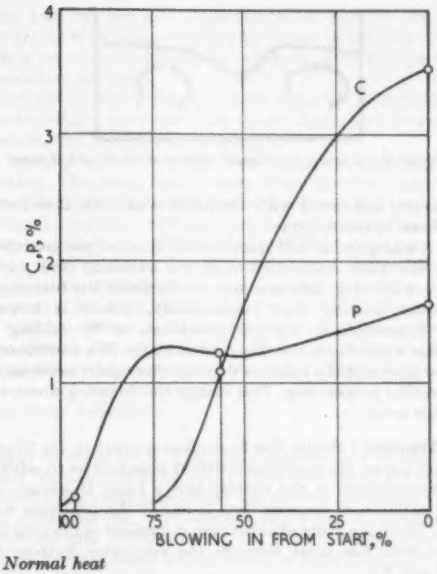
Some designers have suggested that the peripheral speed should be kept constant, which for a 100-ton vessel might mean that the unit need rotate at only 20 rev/min. We have made two stabs at the problem. In the first instance we assumed a simple circulation with a shear velocity between slag and metal proportional to rev/min at vessel dia. We decided that we could treat only those processes controlled by diffusion across the slag–metal interface, and we wrote down the appropriate diffusion equation which involved the film thickness.

Film thickness could be estimated in terms of the shear velocity and thus we derived an equation for refining time. If a 100-min tap-to-tap time could be achieved at 28 rev/min in a 26-ton vessel, we estimated that 35 rev/min would be necessary for the same tap-to-tap time in a 100-ton vessel. Furthermore, on this simple boundary-layer theory, refining time ought to be proportional to $(\text{rev/min})^{-0.9}$.

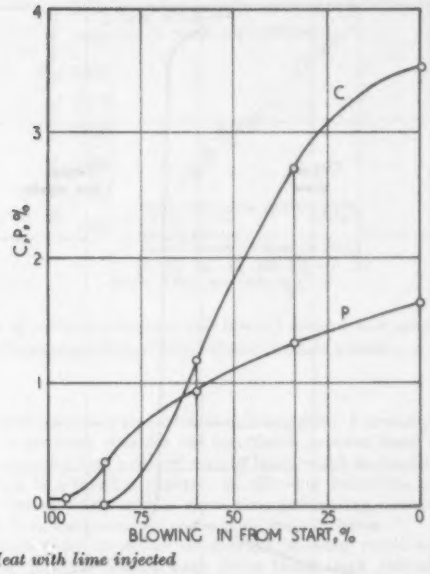
The second approach was by means of models with two fluids. We soon found that we could not simultaneously satisfy Reynolds, Froude, and Weber criteria and we had to compromise. The aim was to find an equation defining a similar degree of mixing. It was possible to estimate the speed at which the undertow had just commenced and the speed at which undertow was fully established. A Power number was defined as a power function of the Reynolds, Froude, and Weber numbers; and if we assumed similar degrees of mixing would give similar refining times, we now estimated only 24 rev/min for the 100-ton vessel, as against the known 28 rev/min for the Domnarvet unit. It was decided to design the Consett vessel for 35 rev/min as indicated by the boundary-layer theory. Depending on the degree of development of undertow it was to be expected that this would give us some possibility of shortening refining time.

More recently our friends at Sollac, especially Monsieur Rocquet, have carried out an elegant cold model study of the chemical reaction between two liquids, with controlled variation of the viscosity and surface tension as well as the concentration. Cases were studied where the rate-controlling factor was diffusion from the upper layer on the one hand, and from the lower layer on the other. In either case the refining time was found to be proportional to $(\text{rev/min})^{-1.1}$ power. The application of dimensional theory predicts about 31 rev/min for the 100-ton vessel. Experience at Sollac vindicates this laboratory work and a statistical study of Domnarvet data shows that refining time is inversely proportional to rev/min for a given size of vessel. Thus, we are beginning to achieve some kind of agreement between pure theory, mixing experiments, cold models with chemical reaction, and full-scale practice.

Turning to the paper of Holmes and Thring, the gas circulation in a converter is likely to be greatly modified, or even




**E** *Normal heat*




**F** *Heat with lime injected*

suppressed, by foaming. Foaming is likely to occur if medium- or high-phosphorus irons are refined. Early dephosphorization demands a fluid slag, rich in FeO, in contact with a high-carbon melt. Foaming almost invariably results in some degree. Hence, where a volume of 0·8 m³/ton has been used in classical low-phosphorus LD practice, high-phosphorus processes may demand vessels with volumes in excess of 1 m³/ton. In our own pilot plant at Stockton we can successfully blow a 2-ton low-phosphorus iron charge at a blowing volume of 0·5 m³/ton. With medium phosphorus and lime blowing we have to halve our charge if we are to retain the foaming slag adequately in the vessel. The presence of this foam must modify all the flow processes, gaseous and liquid, in the vessel, and if Professor Thring can devise any means of investigating these phenomena everyone will be grateful.

One final point about fluid slags and foaming: in the early days of our pilot plant we had great trouble with short lance life. The nozzle was apparently scarfed away by molten droplets of iron (not slag). The whole end of the nozzle was coated with a layer of very low carbon iron welded to the copper. As soon as we found how to attain fluid slags earlier in the blow this trouble ceased. Now we are mainly working with foaming slags with the lance effectively immersed in the slags and nozzle wear is negligible.

Professor Thring also mentioned the study of two-liquid systems. We have found, as has Dr Kootz, that flow pattern in two-liquid models is quite different from that with only one liquid. It would be interesting to study momentum transfer across a boundary as a function of inter-facial tension, viscosity, and density ratios. I should also be glad to know how he hopes to look into operating furnaces. I have tried and the fume always defeats me.

Mr van Langen's paper is another interesting study of two-liquid systems with particular reference to foaming. He suggests blowing at an angle and I would ask whether, quite apart from its effect on refractory life, the splashing might not be serious. Will he not merely replace one difficulty with another? He tells us that he has found a layer structure in an actual desiliconizing vessel and I should like to know how sharp this is. Are there two distinct layers or is there merely a relatively shallow concentration gradient?

Finally, there is his cryptic remark that the set-up of a sloping lance was never tried in practice because 'a method was found to lessen foaming by controlling the foaming properties of the slag'. Foaming is a subject of the greatest interest to all of us and it would be valuable to know why such troubles were encountered at IJmuiden with a low-phosphorus practice and how they were overcome.

Mr **Holden:** Mr Young asked how much influence the work at Swinden Laboratories had had on the original design of the Ajax furnace. As far as we are concerned, the design was 100% Appleby-Frodingham's although how much Mr Jackson and Mr Kemp were influenced by reports from the laboratories and by conversations with the research staff it is impossible to say.

As regards the diagram showing the vitiation of the oxygen jet as a function of distance from the nozzle, standard entrainment formulae were used, corrections being made to allow for the fact that with supersonic jets virtually no entrainment occurs in the sonic core. The main point we wished to make here was that for a given nozzle design different oxygen pressures produced a different oxygen/$CO_2$ mixture at the surface of the melt.

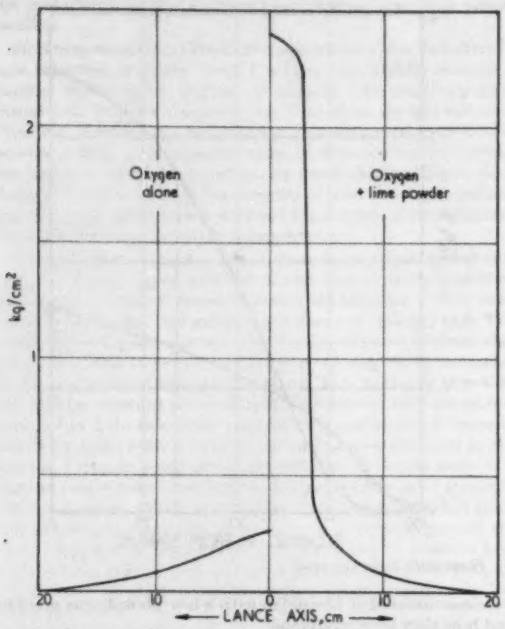
I was very surprised at Mr Young's suggestion that nozzle design does not affect the discharge coefficient. Personally, I cannot believe this.

Mr **Holmes:** I was asked about the photography. This is tricky. I have observed oxygen in one or two places, particularly The Steel Company of Wales; I looked into the furnace and could see quite clearly. There is a great deal of fume inside the furnace, but most of it is at the top of the furnace and there is a clear space underneath where one can see. We hope to see the depression, but we have not gone very far. We have taken pictures inside a furnace at Dorman Long with small success. We went there before they started to try the instruments out, and the film was taken in a furnace not burning oxygen; the pictures of what was going on inside were not very good. When we have the technique right I think we shall get some fairly useful pictures; it is purely a practical problem and we hope to overcome the difficulties. In Mr Kootz's film, once the spraying had started the fumes covered everything, but in the open hearth one can get inside and see what is going on.

I was asked about fuming in the converter. My mention of the converter in the paper is a report of someone else's work and we are not working on this point. I agree that fuming in the converter makes a great difference to the flow patterns.

Mr **Kun Li:** I was asked how much advantage has been taken of the fact that the lance produced less splash than the jet. As far as I know, the lance is above the bath.

Dr **J. H. Chesters** (United Steel Companies Ltd): The simple answer to Dr Young's question is that the practical work was




**G** *Jet momentum, per unit of surface and time at a given distance from lance tip*

done first and the research followed. The Ajax furnace was designed by Appleby production and engineering staff, though considerable assistance was gained from water-model work carried out in the Metallurgical Department (Research) at Appleby-Frodingham. The work by Holden and Hogg started later and was intended to provide a fundamental background for all future work on lancing and jetting.

With regard to the quantitative techniques of splashing, Mr Holmes would, I think, be interested in a method developed in the United States in connexion with such problems as the icing of aircraft. Briefly this consists in covering the aerofoil, or other shape, with a piece of blotting paper and using a soluble dye in the impacting droplets. After a test run, the blotting paper is cut into strips and the amount of liquid picked up determined by placing the strips in water and making a colorimetric determination of dye concentration. It is possible in this way to draw characteristic curves showing the distribution of droplets over a surface.

During a recent visit to Japan, I heard of an even more novel method that has been used successfully in connexion with water model studies on LD vessels. Some of you may remember as boys purchasing sweets, known in Japan as Chinese marbles, which changed colour as you sucked them, having been produced by a series of coatings of different-coloured sugar. In the Japanese work these marbles were suspended at various points within a water-model converter; after a period of blowing the marbles were inspected and the severity of conditions at particular points deduced from the colours shown by the marbles.

Mr **van Langen:** Dr Young asked about refractory wear. I cannot answer, because we have insufficient data. We have made only about ten tests, and such a short period does not spoil the refractory. I agree that wear will be severe if one works continuously with a slant lance, but we intend to use not a straight lance in a slant position but a vertical lance with slant nozzle, so that it can be rotated to use all the refractory.

Turning to the desiliconizing vessel, we have taken a sample throughout the depth of the vessel being blown. After the operation with a vertical lance in the upper half of the bath the silicon content was nearly zero but at the bottom the original silicon content was still there. We have also done trials with a

**H** *Liquid flows when one-liquid system with air jet is used*

slant lance, and found with the latter a uniform distribution right down to the bottom.

The foaming in our LD vessel is clearly some gas production within the bath, connected with the viscosity and surface tension of the slag. One can hope to diminish the foaming by continuous stirring, e.g. mechanically, which is however nearly impossible in the circumstances, or by adding the materials which form the slag continuously. We continuously add the lime and the calcium fluoride (fluorspar) necessary to produce the proper slag. This brings the foaming down to a workable level.

M. **B. Trentini:** I should like to confirm a point in Dr Kootz's excellent paper. He mentions different possibilities to advance dephosphorization in the bottom-blown basic Bessemer converter: addition of crushed lime is one of the solutions mentioned. There is a more efficient one: it consists of blowing lime powder with the blast through the converter bottom (*see* Figs.*E* and *F*).

In a normal blow (Fig.*E*), at the end of decarburization we still have about 1·3%P, starting from 1·8% in hot metal. In a blow, with all the lime injected as powder through the bottom (Fig.*F*), we get only 0·3%P at the end of decarburization, proving that dephosphorization has been well advanced.

We are quite sure that it is possible to go further and to finish dephosphorization at the same time as decarburization, and even before, in the bottom-blown basic Bessemer process. But we did not continue, because we found that basic Bessemer steels made with lime powder injected through the bottom were too high in nitrogen. It was in order to keep the benefit of this early dephosphorization due to lime powder and to avoid nitrogen pick-up coming from the blast, that we developed the method of blowing lime powder in a pure oxygen stream (OLP process).

I should like to add a few words about the penetration of jets carrying lime particles in suspension. As Dr Kootz notes, such jets have a very strong penetrating power; this is shown by the two curves in the paper. It must be noticed however that solid particles are gathering speed very slowly compared with gaseous molecules, and consequently these particles need a given lance length before reaching a velocity equal to that of the oxygen stream. The high momentum of such jets is shown on Fig.*E* corresponding to a lance 9 m long and 48 mm dia. Oxygen flow is 60 m³/min, and lime 120 kg/min, i.e. a lime concentration of 2 kg/m³. Pressure at lance tip is 7 kg/cm². The momentum per unit of time and of area and at a distance of 1 m from the lance tip, is shown on Fig.*G* and compared to that of a stream of pure oxygen without lime powder. One can see how great is the difference. Changing lime concentration affords a very flexible way of changing penetration of the jet. For example in our OLP industrial converters, for high-phosphorus hot metal (1·8%) lime concentration may vary from 0·4 kg/cm³ to 10 kg/cm³, i.e. a ratio of 25. Lime flow over ¼ ton/min is used. It can be understood that this difference in penetration power is much greater than that obtained by changes in venturi nozzle shape. No venturi nozzle is necessary in the OLP process.

In such a process, the lime powder equipment is of primary importance and must be very well fitted: in particular an irregular flow with pulsations would lead to heavy spittings and bad refining results.

Referring to Dr Holden's paper I should like to comment on Fig.14 in his paper: with an inclined lance and two layers a given flow pattern is obtained. This is just the opposite of the one shown by Dr Kootz with a vertical lance and one layer, and confirmed by other studies: for example by Mathieu[3] in

Belgium and by our own experiments at IRSID. Did Dr Holden try to blow with a vertical lance and in that case what is the flow pattern? Do we obtain a reversal of the flow pattern with increased jet flow?

Dr Holden mentions that the mass transfer coefficient for surface blowing is controlled only by the Reynolds number at the surface. But how can we calculate it?

We entirely agree with Dr van Langen concerning desiliconizing. The same results were found in work made by M. Leroy at IRSID and published[3] a few years ago: there was a decrease of silicon in the top layer and no silicon change at the bottom. But that applies to a very weak jet of oxygen and without any very strong decarburization, and the problem is therefore rather different from top-blowing for making steel.

Concerning Mr Kun Li's paper, the fact that the freshly made solution differs in behaviour from the older solution may be due to impurities coming from the air blown, thus changing the surface tension of the water. That may be an explanation of the difference in the behaviour of foaming between these solutions.

Mr **Hogg:** In reply to M. Trentini, the statement made, that the mass transfer coefficient for surface blowing is controlled only by the Reynolds number at the surface, is based on the form of equations (10), (11), and (12) of the paper. In calculating mass transfer coefficients, it has been assumed that the characteristic dimension which occurs in both Sherwood and Reynolds number is identical, and, therefore, the absolute value of $R$ need not be known.

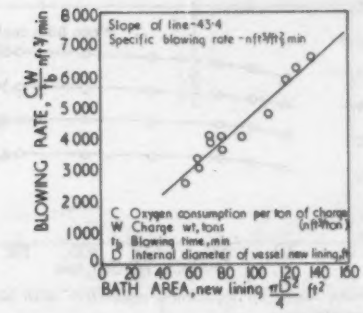
The differences in flow patterns observed by ourselves compared with the references cited by M. Trentini arise because we have used a two-liquid system. In Fig.14*a* of the paper which is for a low jet flow, the pattern is essentially the same as the one shown by Dr Kootz. At high flows, Figs.14*a* and 14*c*, the bow wave in the water immediately after the depression is held back by the oil layer and, consequently, a steep-sided wave is formed, which would be unstable in air. The effect of this steep-sided wave is to deflect the water stream downwards and so reversal of flow occurs.

It must be remembered that the direct action of an air jet on a liquid surface is local to the depression and, consequently, changes in the surface topography behind the depression can have marked effects on the flow pattern. Since the stable topography of a two-liquid system is very much different from that of a single-liquid system, interfacial tension, viscosities, and densities are all factors which will affect the topography; it is not surprising that different flow patterns are observed.

Mr **Kun Li:** The point about changing foaming conditions because of impurities in the air is well taken. I was merely trying to point out that as foaming conditions change, the splash pattern changes too.

We have done work at Jones and Laughlin in connexion with the LD process, and if a one-liquid system with an air jet is used, the liquid flows are as shown in Fig.*H*. The minute there is a second layer (oil or any other liquid with slightly different surface tension and viscosity) a reversal of that motion takes place, which becomes more pronounced as the jet flow rate is increased. We attribute this reversal of motion to the drag forces between the second and first layers. The jet has a tendency to push the slag layer away from it, but by gravitational force it tends to come back, with surface tension force, to its original shape, dragging the liquid underneath it. In that way the reversal motion is created.

Dr **A. G. Raper** (Davy-United Engineering): At the present time experience on top-blown converters is limited to converters of less than 100 tons capacity. However, converters of 200 tons capacity have been ordered and others of 300 and 400 tons are projected. I should like to describe a design method for such large capacity converters based upon the extrapolation of results published for existing top-blown converters. This description will be limited to the case of low-phosphorus hot metal.




**J** *Plot of calculated blowing rate* ($cw/t_b$) *against bath area for top-blown converters. Published data from 11 plants*

It is first necessary to correlate existing data. For this purpose it is assumed that for the top-blown process there is a specific reaction rate per unit area of bath which is consistent with good top-blowing practice in allowing minimum conversion times, while at the same time preventing excessive ejection from the converter and a poor slag condition.

Reaction rates in terms of average blowing rates were, therefore, plotted against bath areas using data published from 11 top-blown plants. Bath areas were based upon the internal dia. of the converter with a new lining.

The results of this correlation are shown in Fig.*J*. From the slope of the line it can be seen that the specific reaction rate for all top-blown converters of less than 100 tons capacity is 43·5 ft³/ft²/min. It is assumed that this value of specific blowing rate will also hold for converters with a capacity in excess of 100 tons.

Having established the specific blowing rate, it is necessary to fix a metal bath depth for a given capacity converter before blowing times can be determined.

It is clear from the graph that the metal depth should be small to give a high surface area and therefore a high conversion rate. However, a given head of metal is desirable to prevent bottom damage and to allow adequate circulation of the bath. Results obtained on existing converters indicate that a depth of 42–60in fulfils these requirements.

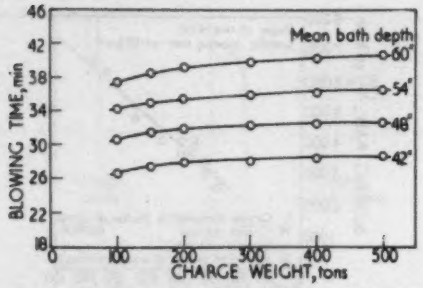
Using this range of metal bath depths, the bath surface areas can be evaluated for a given capacity converter. These in turn can be used with the specific blowing rate to determine actual blowing rates and hence the conversion or blowing time required for the converter. Results are tabulated in Fig.*K* showing blowing times for various capacity converters working on low-phosphorus hot metal with differing bath depths.

Production rates can be evaluated using the blowing times shown and also using the time occupied by charging and tapping, etc., which can be calculated from any given layout.

Finally it should be emphasized that the design method outlined is only approximate and in practical design several corrections must be allowed for: a correction must be made to allow for the ineffective bath coverage by the oxygen jet. As the blowing rate is increased the jet momentum also increases, which in turn means that the metal bath depth should be increased slightly to prevent bottom damage. As the jet momentum increases there will be a greater tendency for ejection from the furnace and an increase must be made to the overall vessel height.

Mr **G. Danielsson** (The Grängesberg Company): I should first like to recall a drawing (Fig.*L*) of a steelmaking vessel, published by Sir Henry Bessemer about 1890, which he proposed should be used for the refining of iron with oxygen.

Referring now to the paper by Holden and Hogg in which is given an estimate of the amount of mechanical energy supplied to a steel bath in an oxygen vessel; assuming that 25 tons of iron containing 4%C is refined in an LD converter in 15 min,




**K** *Conversion times for top-blown converters with charges in excess of 100 tons*

the stirring effect of the carbon monoxide bubbles formed can be calculated by the simple $P \times V$ formula to about 2400 kW provided the bubbles all rise from the bottom of the vessel.

As this is not the case (the foaming of slag in oxygen vessels is a well known but not always desirable phenomenon) the actual stirring effect is lower but still substantial. It is also interesting to note that the energy input for a conventional Bessemer blower for a vessel of the same size, and at the same rate of carbon oxidation, is almost the same. The stirring effect of the rotation of a Kaldo vessel and that of an external jet is of another and smaller size, as pointed out in the paper.

Mr **A. W. D. Hills** (Imperial College): I should like to speak on the nature of the mass transfer coefficient. In their paper Holden and Hogg said that the mass transfer coefficient is the function of Reynolds number, but this is a simplification of the actual state of affairs.

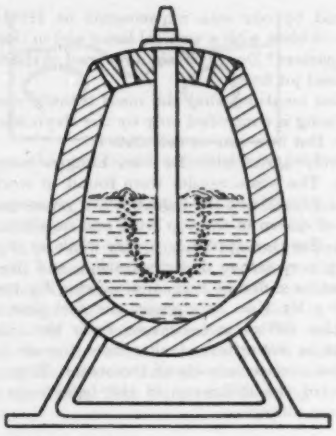
The convective mass transfer process can be described by an equation in which the mass flux at a surface is expressed as being proportional to the bulk concentration difference between the two phases, and the constant of proportionality is known as the mass transfer coefficient. This equation is analogous to the equation for convective heat transfer, in which the heat flux at a surface is expressed as being proportional to the bulk temperature difference between the phases and the constant of proportionality is known as the heat transfer coefficient.

There is, however, a fundamental difference between the two constants of proportionality. Heat transfer at a surface does not affect the velocity field around the surface, and so, with constant fluid properties, and any given geometry, the heat transfer coefficient is a function of the Reynolds number only. However, when mass transfer occurs, a finite velocity exists normal to the surface, the value of which changes as the rate of mass transfer changes, and so the velocity field around the surface is affected by the mass transfer rate. Consequently the mass transfer coefficient is a function of the Reynolds number, and of the concentration difference.

This effect is not particularly significant at the low mass transfer rates found in low-temperature chemical engineering processes, but is significant at the high rates to be found when oxygen is absorbed in liquid steel. Thus, if any further theoretical work is undertaken in this field, it will be necessary to consider the mass transfer coefficient as a function of the Reynolds number and of the concentration difference.

Dr **T. P. Colclough** (BISF): There is one grave danger in the work being carried out in this model experimentation: In most of the model work which has been done so far we have had a gas being blown on to the surface of a liquid in which the mass of the two elements remains constant. In the case of oxygen being blown into steel, the impact material is consumed and therefore there must be a marked change in pattern resulting from the fact that one of the elements disappears.

The second point which has a bearing, which is not illustrated in the models, is that as the oxygen disappears when it is inside a melt, there is an intense local generation of temperature which in turn must give rise to currents in the liquid.



**L** *Old steelmaking vessel*

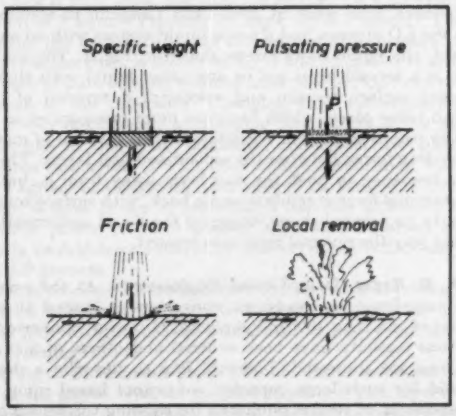
The third element is that as the oxygen disappears it is replaced by double its volume of carbon monoxide, and in trying to escape, that too must tend to form currents in opposing directions.

These three factors have not yet been indicated in these model experiments and, much as one hesitates to add to the load of the workers in this field, they must be given attention if the correct inferences are to be drawn.

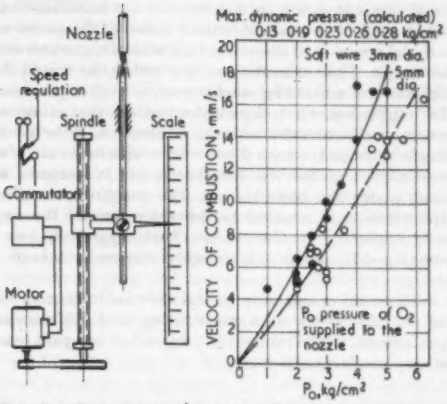
Dr-Ing. **H. Hauttmann** (Vereinigte Osterreichische Eisen und Stahlwerke AG): We have heard of the divergency between the results of the model tests and practice. The impossibility of adapting the conditions of the model tests to the conditions given in practice in so many important respects has discouraged us from granting too much importance to the model tests when we were developing the LD process. In Linz, model tests with air on water and gaseous hydrochloric acid on solutions of caustic soda were carried out in 1949.

To meet the conditions given in practice when carrying out model tests it must be recognized that there are four main causes which may create movements in a bath affected by the reactions of a gas jet acting on the bath surface, e.g. oxygen on liquid iron, as shown in Fig. *M*.

(i) Oxygen blown on the surface may cause local alterations of the specific weight owing to the changing composition and temperature of the iron in the reaction field. The direction of the movement in case of increasing or decreasing specific weight is shown by indicators.




**M** *Movements of a liquid, caused by a gas jet acting on the surface*




**N** *Velocity of combustion, reaction of $O_2$ with Fe*

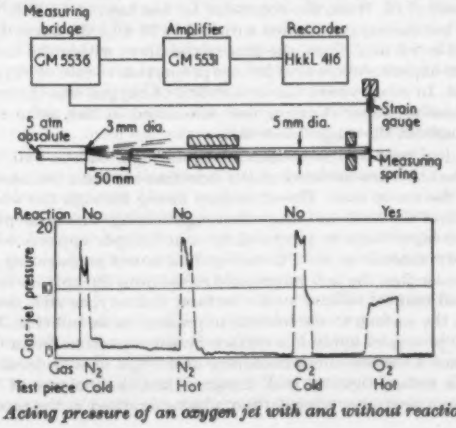
(ii) Liquid reaction products or gases thrown away in radial direction from the reaction field may affect the bath surface by friction, thus causing a movement.

(iii) A movement of the bath is also caused by the replacement of that part of the iron which is removed in form of oxides or vapour owing to the reactions with the oxygen jet.

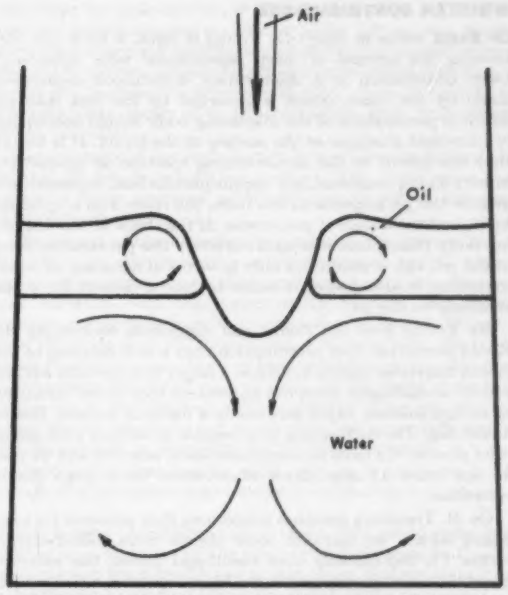
(iv) Of greatest importance are the effects of the variations of pressure of the oxygen acting on the bath surface; these are caused by short local interruptions of the oxygen jet by the reaction products, or by non-reactive particles whirled in by the oxygen jet. There is a marked difference in pressure if oxygen is absorbed in the reaction field or if there is no reaction. The variation of pressure has the effect of a pump. Also the pressure developed by the evolution of carbon monoxide in the reaction field is to be taken into consideration.

The velocity of the reaction of oxygen on iron is of great importance. Calculations yield very high velocities depending upon pressure and temperature. According to our calculations the absorption of oxygen of 1500°K at normal pressure ranges to about 6 l/cm²/s. (Calculations recently published by Teakes[4] give velocities of the reaction of oxygen and iron twice as high.)

Recently I have tried to determine the velocity of reaction in a simple experiment as shown in Fig.*N*. Oxygen of different pressure is blown by a nozzle perpendicular to the cross-section of an iron rod (low-carbon steel) which is movable in the direction of the axis of the jet. During the reaction of oxygen on the cross-section the distance of the burning end of the iron rod from the nozzle is kept constant by turning a screw. The velocity of the movement of the iron rod indicating the velocity of the reaction is determined. The reaction products,




**O** *Acting pressure of an oxygen jet with and without reaction*

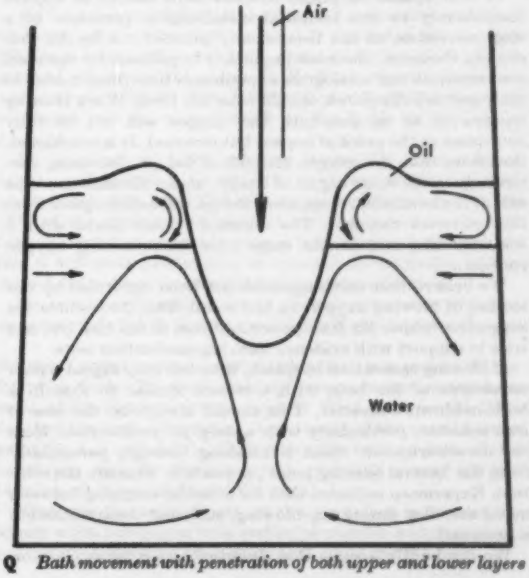



**P** *Bath movement with penetration of upper liquid layer only*

dropping down from the burning end of the rod, are immediately cooled in a water-filled pan to observe melting of the iron which may happen if pressure of oxygen exceeds a certain limit (not shown in the figure). Molten iron indicates an unsatisfactory result.

Experiments in order to determine the pressure acting on the surface of the iron rod (cross-section) in case of reaction (burning) and in case of no reaction have proved that the acting pressure is twice as high if there is no reaction occurring, compared with the acting pressure while reaction takes place. This result is in accordance with the calculations. The simple apparatus used for these experiments is shown in Fig.*O*, which also gives results in form of diagrams.

At present we are carrying out model tests in various forms as well as blowing tests in full size vessels. I hope to be able to report on the results of these tests within a few months.




**Q** *Bath movement with penetration of both upper and lower layers*

## WRITTEN CONTRIBUTIONS

Dr **Kootz** wrote in reply: Dr Young is right, if he is not contrasting the process of 'deep penetration' with 'splashing'. Deep penetration is a deliberately determined depression, made by the blast, which is governed by the fact that the depth of penetration of the displacing body should correspond to its widest diameter at the surface of the liquid. It is known that the extent of the decarburizing reaction as against the other refining reactions, e.g. dephosphorization, increases, the greater the jet impacts on the bath, the more iron is splashed by it, and the deeper it penetrates. If the shape of the displacing body (blast) can represent correctly the penetration force of the jet, this is useful not only in terms of accuracy of representation; it also makes it easier to give a desired force and efficiency to the jet.

Mr Young does not follow our suggestion concerning the Kaldo converter. Our presumption that a fast rotation of the Kaldo converter makes available a larger free metallic surface is only a conclusion from the hypothesis that decarburization at an unhindered, rapid rate needs a metallic surface, free of liquid slag. The surface can then remain in contact with gas or solid phases. We have no model-studies of our own and we also do not know of any direct observation on a large Kaldo converter.

On M. Trentini's question concerning flow-patterns for two-liquid layers, we can cite some results from model-experiments. On top-blowing over two-liquid layers, the reversed gas-stream always imparts to the blown medium a movement, such as is obtained on blowing over a single-liquid layer. If the stream blows only into the upper liquid layer then the result for both the layers is simple. The upper layer, set into rotation by the gas-stream, transfers its movement to the layer underneath and there creates a rotation in the opposite direction (Fig. *P*). It becomes more difficult, when the stream penetrates through the first layer and also enters the bottom layer. It then imparts a rotation, in the same direction to both liquid layers, and the friction between these two layers counteract it. If the jet penetrates the lower layer sufficiently it creates there a rotation in the same direction, as when blowing on a single liquid, The movements in the lighter upper layer will only be determined at a greater distance from the stream, by the friction between the two liquids. In a limited area, in contact with the reversed blast-stream, a pulsating movement is created in the upper liquid layer. There the effect of rotation of the lower liquid encounters the movement transmitted to the top liquid layer by the blast-stream (Fig. *Q*).

Of course, such simplified model-studies cannot be applied immediately to the technical–metallurgical processes in a steel converter, as has been clearly pointed out by Mr Colclough. However, the most important hypothesis for the steel converter, as our analogous experimentation from model to the pig-iron ladle shows, should take this form: When blowing oxygen on to an iron-bath the oxygen will not be fully consumed at the point of impact but reversed. It is considered, therefore, that the oxygen content of the jet decreases, particularly in the outer region of the jet, as the distance from the exit of the nozzle increases, since the jet will entrain gases from the converter chamber. The reversed stream draws with it iron and slag and at this stage loses its remaining oxygen content.

We believe that this suggestion has been confirmed by our studies of blowing oxygen on hot metal. This contradicts the suggestion which Mr Hauttmann outlines in his case (iv) and tries to support with evidance from his combustion tests.

If blowing causes iron to splash, then one may expect a poor movement of the bath with a stream similar to that in a bottom-blown converter. This should always be the case if iron splashes, particularly with a deep jet penetration. Here the decarburization which is breaking through, particularly from the 'central burning point', appears to intensify the rotation. Experience indicates that for a fast intermixing between metal and slag during top-blowing, sufficient decarburization is necessary.

We can hardly assume that decarburization takes place on the wall of a converter, as it does with the solidification of a rimming steel in the mould, rather than at the point where pure metal comes into direct contact with the gaseous oxygen under the jet. The bath rotation observed in the mould during solidification of a rimming steel is specific to that process.

The suggestion, that dephosphorization, occurring simultaneously with decarburization, requires a retardation of boiling in its region, means that two reaction areas are needed. One reaction area for the decarburization is assumed to be situated under the blast stream. The reaction area for dephosphorization is situated peripherally around the oxygen stream, impacting in the centre. This suggestion has only schematic value and is only roughly correct in a large converter.

A bath rotation opposite to the reaction observed in the model, in the terms of a penetrating and self-consuming oxygen-stream, would render the proposal of separate reaction areas very much more complex.

Mr **C. E. Sims** (Battelle Memorial Institute, Columbus, Ohio) wrote: In the November 1960 issue of the *Journal* there are five very interesting articles[5] dealing with the theory and mechanics of oxygen steelmaking processes. I am, however, disturbed by a concept that appears to permeate and influence all of these studies, a concept that I believe to be erroneous and misleading. It is that some form of imposed mechanical stirring or agitation is necessary for the success of a pneumatic steelmaking process or at least for high efficiency in such a process. I base my contrary opinion largely on studies made over ten years ago on surface blowing of basic pig iron in a basic-lined converter.[6]

The belief seems to have originated with Henry Bessemer himself and has persisted until now. In bottom-blowing practice, of course, the passage of the gases through the metal bath provides all of the turbulence needed. With surface blowing, however, it was presumed that some auxiliary provision for agitation would be necessary. Tropenas proved that this was not true about 70 years ago. The originators of the LD process apparently felt the need for induced turbulence when they specified a very high speed oxygen jet which would penetrate deeply into the metal bath. The potency of the carbon boil itself has been widely overlooked.

With the above-mentioned experimental converter, the tuyeres were set at an angle of $\pm 14°$ from the horizontal, the air jet had a nominal linear speed of 330 ft/s, and the pressure in the windbox was less than 3 lb/in$^2$. This was scarcely enough to penetrate the slag layer, yet, when the air blast was at the rate of 1500 ft$^3$/m/ton of hot metal, the carbon was eliminated at the rate of 0·5%/min during the carbon boil and a blow was complete in 12 min.

When the jet velocity was increased to 430 ft/s without an increase of air volume, there was no noticeable change in the operation or the length of the blow. When the air volume was increased to 2000 ft$^3$/m/ton, the flame drop came in 9 min instead of 12. When the volume of air was kept at 1500 ft$^3$/m/ton but the oxygen content enriched to 25·6%, the flame drop came in 8·5 min. Thus, the time of the blow, within the limits of the experiments, was in inverse proportion to rate of oxygen input. In other words, the availability of oxygen was the rate-controlling factor. Carbon was eliminated at the same rate throughout the range 3·2–0·05%.

It has been well established that, during a carbon boil, the CO bubbles are initiated at the interface between the hearth and the metal bath. Therefore they sweep through the whole depth of the bath and cause thorough mixing. The concept of a two-layer bath as proposed by van Langen appears completely untenable. An OH carbon boil is self propagating, in the sense that the boil carries cold metal from the bottom to be heated and reoxidized at the surface, and oxygen-rich metal from the surface to the bottom to produce more bubbles. The same principles apply in a surface-blown converter. In an OH furnace a carbon elimination rate of 0·5%/h is considered to give a rather vigorous boil. Imagine then the violence of the boil in a converter when carbon is being oxidized at the rate of

0·5–0·75%/min. In the experimental vessel, the boil could be observed, and it gave the distinct impression that no additional turbulence was needed.

Calculation shows that, when carbon is being eliminated at the rate of 0·5%/min, the volume of CO gas formed, at the temperature existing in the converter, is about 1500 ft³/min/ton of metal. With so much gas released below the surface, the contribution of the jet to stirring is puny by comparison. Such extreme agitation also provides ample surface for the absorption of gaseous oxygen. In some good American practice in the LD type of converter the jet nozzle is as high as 70in above the bath. At this height the penetration is probably not very deep. Nevertheless, the reaction rates are fast, 20 min blowing time for over 80 tons, and the consumption of oxygen close to theoretical. Another reason why jets cannot be relied on for stirring is the extremely rapid absorption of the oxygen by the bath.

It would seem that Dr Kootz is discussing sequence of reactions as much as equilibria. In the Thomas converter no significant dephosphorization is attained until the afterblow. That is because the air first contacts the iron and the oxygen is all reacted. The slag can have only what the iron will give up. Until silicon, manganese, and carbon are depleted, they preempt the oxygen. Only after the flame drop, when there is nothing left to burn but iron and phosphorus, can the slag become sufficiently oxidizing. With the experimental surface blowing, the dephosphorization proceeded almost exactly parallel to the carbon elimination. In this process the air contacted the slag first and the latter was kept in an oxidized condition throughout the blow. The 'hard' jet of Dr Kootz approached the conditions of bottom blowing while the 'soft' jet allowed some direct reaction of the oxygen with the slag.

One apparent consequence of the 'hard' jet is the requirement for high-purity oxygen to obtain low-nitrogen steel. With the experimental top blowing and its 'soft' jet, nitrogen contents as low as 0·002% were attained with the use of air.

Experience with oxygen lancing in OH and electric furnaces indicates that no one has been able to inject oxygen at a rate faster than it can combine with the metal. The same thing seems to be true for jets while a boil is in progress. There is no evidence that there is much $CO_2$ in the effluent gas of an LD converter, to say nothing of unreacted oxygen. Some rotor processes use an auxiliary jet to convert part of the CO to $CO_2$. What is the reason for the concern over reaction rates and oxygen efficiency? It appears that Messrs Holden and Hogg may have an excellent analysis of a non-existent problem.

We are, nevertheless, appreciative of these fine studies. They have come at an opportune time to be of help in some studies concerning the action of jets in producing smoke during blowing. Also, in speaking of 'hard' and 'soft' jets, some limits should be set because there is reason to believe that too soft a jet, say under 200 ft/s, may allow the slag to chill and stop the reaction.

Dr **Kootz** wrote in reply: I agree with Mr Sims, that even a severe jet cannot by itself impart a sufficient movement to the bath. To mention movement, however: this travels in a direction which is determined by the reversed stream and intensified by the peripherally sprayed liquid particles.

Also, it is possible to blow so poorly that no iron is splashed. Nevertheless, from our experience with a large converter we know that, with such blowing, oxygen may be absorbed, at least in part, by the slag and through the slag medium.

If, however, one blows in such a way that no splashing appears, the decarburizing reaction will die out completely. As soon as the bath has been thoroughly supersaturated with oxygen, it may break through explosively. We have experienced this phenomenon with a 30-ton converter.

Only when blowing is so severe that metallic iron is struck and sprayed, will noticeable decarburization begin.

If splashing occurs with an oxygen jet it can be considered as a poor one. In that case, decarburization also will be only poor, and on such a blow the slag will be enriched by iron. The more severe the jet, the more rapid the decarburization and the better the bath motion. With a control of the jet, such as has been usually applied up till now in the LD-process, decarburization is so rapid that the largest amount of oxygen will be claimed by carbon. If basic Bessemer iron is refined with such a severe jet, the reaction process will occur, dephosphorization will take place mainly after decarburization, as in the bottom-blown converter.

The intensity of the bath motion is undoubtedly dependent on that of the decarburizing reaction. This determines the extent of those reactions, which are transferred by the slag (dephosphorization).

The extent of the decarburizing reaction has proved to be dependent on the physical conditions created by the blast-stream when impacting on the metallic surface. From this one may conclude that the decarburizing reaction will break through, particularly from the 'central burning point'. If, however, the gases from the decarburizing reaction leave the bath under the oxygen jet, then one may probably expect that the liquid masses lifted and pushed away by the rising gases will stream out to the periphery of the converter. The bath motion which the jet attempts, but which does not occur sufficiently without support, is intensified by the decarburization.

These suggestions can be valid only as hypotheses, even though they are based upon studies of a full-scale converter.

Messrs **Holden** and **Hogg** wrote in reply: We would point out that we are well aware of 'the potency of the carbon boil', but, as we state in the introduction to our paper, in some cases this is insufficient to produce thorough mixing of the reactants.

At the bottom of page 323 of our paper we state that the energy released from the exothermic reactions is a thousand times greater than the mechanical energy in the high-velocity oxygen stream and consequently the potential energy available from this source is very high.

How much of the energy from the exothermic reactions is converted to mechanical energy is difficult to say, but obviously even if this is only a fraction per cent it could still be the largest source of mechanical energy.

The hypothesis that the carbon boil creates sufficient mixing to render mechanical methods unnecessary implies the boil can be created at will. While this might be true in the purely pneumatic processes it is not true in the electric-arc furnace where induction stirring is sometimes used to promote the boil; neither is it true in the OH furnace. The degree of unmixedness that can occur in an OH steel bath is well illustrated in a recent Russian publication,[7] which shows a falling off of carbon content from the hearth to the bath surface.

Mr Sims also asks what is the reason for concern over oxygen efficiency. We realize that in the LD converter the oxygen efficiency is generally very high, about 95%; however, such a state of affairs did not obtain in Mr Sims experimental converter where 3600 ft³ of $O_2$ (18000 ft³ of air) per ton was used compared with less than 2500 ft³ in the Kaldo or 1500 ft³ in Ajax.

In our paper we point out that in the OH furnace when using a submerged lance there is an optimum blowing rate which varies with lance size. When it is considered that about 80% of the world's steel production is processed in the OH furnace, and that oxygen lancing is being increasingly applied, this is sufficient justification to warrant investigation of the factors controlling the efficiency of oxygen utilization.

We would add that we are in general agreement with the remarks made by Mr Sims regarding Dr Kootz's paper.

Mr **van Langen** wrote in reply: I should like to point out the following facts. The desiliconizing process is carried out in a ladle which is about three-quarters filled with metal. The depth of the bath with respect to the width of the vessel is very great (1 : 1.1) and it is unlikely that the bottom part of the metal can actively partake in the reactions caused by the blowing of oxygen on top of the metal.

Moreover the only object of the operation is to remove silicon while burning as little carbon as possible and, therefore, not many CO bubbles are formed that could stir the bath.

As simultaneous samples taken after vertical blowing at eight different depths have shown us that only the upper part of the metal has fully reacted, I think that the layer-formation in the desiliconizing process is sufficiently shown to exist.

In the LD process the circumstances are much more favourable for the stirring action by the formation of CO bubbles on the bottom of the vessel, as suggested by Mr Sims. We have no definite proof the layer-formation really takes place in this process as the sampling procedure used for the desiliconizing process would cost too much production time in this case. Therefore I did not put forward layer-formation as a fact but only as a possible explanation for the two periods of enlarged gas production during the blow. During those periods of about 1 min each, gas production is about one-and-a-half times the mean gas production. There is a possibility that this is caused by the increased mixing of an oxygen rich with a carbon-rich layer.

**REFERENCES**


1. Sir Issac Lothian Bell: 'Principles of the manufacture of iron and steel, with some notes on the economic conditions of their production'; 1884, London, Routledge.
2. F. Mathieu: *Rev. Univ. Min.*, 1960, July, 309–321.
3. P. Leroy and L. Septier: IRSID Publication, 1955, July, Series A, no.101; abridged form in *Centre Doc. Sid. Circ.*, 1955, **12**, no.7, 1383–1402.
4. K. Teskes: *Schweissen Schneiden*, 1956, **8**, 122–129.
5. T. Kootz: *JISI*, 1960, **196**, 253–259; B. S. Holmes and M. W. Thring: *ibid.*, 259–261; J. M. van Langen: *ibid.*, 262–264; J. V. Edwards: *ibid.*, 289–294; C. Holden and A. Hogg: *ibid.*, 318–332.
6. C. E. Sims and F. L. Toy: *J. Met.*, 1950, April; and *Trans. AIME*, 1950, **188**, 694.
7. E. V. Chelischev: 'Carbon elimination and agitation in oxygen-treated steel baths'.


## POWDER METALLURGY JOINT GROUP

The Iron and Steel Institute

The Institute of Metals

### *Powder Metallurgy no. 7*

*The current issue of* Powder Metallurgy, *the official organ of the Powder Metallurgy Joint Group of The Iron and Steel Institute and The Institute of Metals, contains the following papers.* Powder Metallurgy *is obtainable by annual subscription at 25s. (post free) to non-members; members of the Institutes may obtain it for an annual fee of 10s. (post free).*

A discussion on 'The appraisal of powders for pressing and sintering' was held at the Royal Commonwealth Society, London in April. Synopses of the papers discussed, which are published in this issue of *Powder Metallurgy*, are given below.

'*Fundamental properties of particles and methods of sizing analysis*', by H. Heywood (The Woolwich Polytechnic, London). The author has summarized the results of 30 years' research on the properties of powdered materials. These studies have been concerned with powders of all types, but most of the conclusions are applicable to metallic powders. The complex properties of powders can be resolved only by first defining those fundamental properties that can be measured individually; the first section of the paper defines these and shows how they may be combined to assess the more complex properties, according to the nature of the problem and the circumstances of usage. The second section describes the essential features of methods for the sizing analysis of powders, with brief consideration of their characteristics and some indication of recent tendencies in the application of electronic devices and automatic recording.

'*The bulk properties of metal powders*', by P. R. Marshall (Metal and Plastic Components, Ltd, Birmingham). Current methods of sampling and determination of flow, apparent and tap density, particle size 'fillability', and 'hydrogen loss' are reviewed. The general conclusion is that present tests are adequate, but that new tests more suited to powder usage should be devised.

'*Observations on compacts*', by V. T. Morgan (Bound Brook Bearings, Ltd, Lichfield, Staffs). A large number of tests based on observations made on compacts have been devised to evaluate the pressing and sintering characteristics of metal powders. These are summarized under four headings: behaviour during pressing, properties of the green compact, behaviour during sintering, and the properties of the sintered compact. The specifications which set down standard testing techniques are described and reviewed. The principles involved in the various proposed tests are given, together with any limitations or precautions that need special consideration. In a number of cases there is obvious scope for further study and research, and these are pointed out.

'*Measurement of the surface area of powders by the BET method*', by B. C. Lippens (Koninklijke Zwavelzuurfabrieken v/h Ketjen NV, Amsterdam, Netherlands), and M. E. A. Harmans (NV Keuring van Elektrotechnische Materialen, Arnhem, Netherlands). Some experimental aspects of the construction and use of a conventional BET apparatus are discussed. Certain improvements in the method of measuring adsorption and in the size of the equipment resulted in the development of the 'micro BET' apparatus described here. A considerable simplification in the technique of measurement has been attained. The application of the apparatus is demonstrated by examples.

'*A comparative study of methods for particle-size analysis in the sub-sieve range*', by H. F. Fischmeister and C. A. Blände (Jernkontorets Powder Metallurgy Laboratory, Metallografiska Institutet, Stockholm), and S. Palmqvist (Fagersta Bruks AB, Fagersta, Sweden). Eleven powders of widely different properties (various grades of WC, $WO_3$, tungsten, iron, cobalt, $SiO_2$, $Al_2O_3$), considered typical of the raw materials encountered in powder metallurgy, have been studied by 'single-value methods' (apparent and tap density, air permeametry, gas adsorption (BET) ), and by 'size-distribution methods' (electron- and light-microscope sizing, turbidimetry, sedimentation balance (with gaseous and with liquid medium), centrifugal air classification, and sieve analysis). In addition, a series of WC powders having varying degrees of fineness has been studied by air permeametry, gas adsorption, optical reflectivity, turbidimetry, and sedimentation in air, to assess the reliable working ranges of these methods.

The following topics are treated in detail: air-permeability measurements and their relation to the results of BET and other tests; electron- and light-microscope sizing techniques; turbidimetry; and optical reflectivity. A microscopic study of the breakdown of agglomerates in a tungsten carbide powder is reported. The importance of large agglomerates in all work concerned with particle-size distributions is stressed. For highly agglomerated powders the size distribution of the ultimate units (individual particles within agglomerates) is difficult or impossible to determine, but it is pointed out that this 'true' distribution has much less technical significance than that of the agglomerated powder, provided that the degree of agglomeration in which the powder is analysed corresponds to, or can be correlated with, that prevailing in the process for which it is intended.

'*The relationship between powder properties and the pressing and sintering behaviour of beryllium*' by A. J. Martin and G. C. Ellis (Atomic Weapons Research Establishment, Aldermaston, Berks). The paper surveys the existing routes available for the preparation of beryllium powders, and comments on the effect of certain properties, such as particle-size distribution, on the compaction of powders by different techniques. It is emphasized that particle size, degree of oxidation, and overall purity are interdependent variables, and that little attempt has so far been made to study their effects separately.

'*The powder metallurgy of ruthenium*', by R. G. Cope and D. W. Rhys (The Mond Nickel Co. Ltd, Development and Research Department, London). An investigation of the powder metallurgy of ruthenium is described, from the reduction of ammonium ruthenium chloride to the working of sintered compacts. The powder properties measured were specific surface area, by a simplified BET method, and tap density. The dependence of these properties on the conditions of reduction has been determined. The surface area of powders varies from 1–10 $m^2g$/ in the temperature-of-reduction range 700–350°C. The tap density is also variable (1–3 g/cc) and is generally related to the surface area. The effects of compacting pressure and temperature on sintering are described, the progress of sintering being observed by measurements of the 'open' and 'closed' porosity present in samples. Compact densities up to 95% of theoretical can be obtained by sintering at 1 500°C. The selection of powder properties and compacting pressures to be used in the production, by vacuum sintering at 1 500°C, of high-density compacts for working, is governed by the necessity to maintain open porosity during the heating cycle up to at least 1 200°C, as considerable gas evolution occurs at this temperature; at the same time it is essential that good densification shall have occurred even at this stage. These conditions can be met by using powder with a surface area of 2–5 $m^2/g$ and compacting pressures in the range 0·5–25 tons/$in^2$.

Observations on the hot working of sintered compacts indicate that ease of working is related to the surface area of the powder.

'*Relationship between the properties of tantalum and niobium powders and their sintering behaviour*', by Jiří Vacek (Powder Metallurgy Research Institute (VÚPM), Prague). Experiments have been carried out to determine the relationship between the properties of tantalum powder and its compressibility, and to examine the effect of carbon and niobium on the hardness and tensile and electrical properties of semi-manufactured products of tantalum. The influence of the particle-size distribution of niobium powder upon the properties of sintered bars has also been studied, with particular reference to the problem of swelling of the bars during sintering.

'*The effect of surface characteristics on the sintering of uranium and beryllium powders*', by J. Williams, J. W. S. Jones, and K. H. Westmacott (Atomic Energy Research Establishment, Harwell, Berks). Studies of the sintering of uncompacted uranium powders in vacuum have shown that sintering behaviour is markedly affected by the nature of the surface films on the powder. Of the variables in the powder-production route that might affect the nature of the surface films, the leaching stage is the most important.

The deleterious effect of surface contaminants on the vacuum-sintering behaviour of beryllium is demonstrated. During the development of a technique for the production of a stable powder from electrolytic flake, the nature of the leaching treatment again proved to have a marked influence on the sintering behaviour of the resultant powder.

Both sets of investigations were hampered by lack of methods for identification of surface films on powders.

'*Physical methods for investigating the properties of oxide powders in relation to sintering*', by P. J. Anderson and D. T. Livey (Atomic Energy Research Establishment, Harwell Berks). By the application of several modern techniques, a fairly thorough characterization of even the finest oxide powders with respect to particle and crystallite size and shape may be obtained. The application of these techniques is discussed with particular reference to the characterization of a sample of $Mg(OH)_2$ and the oxides prepared from it by calcination *in vacuo*. The techniques described are, however, exacting and time-consuming and while invaluable for any basic study cannot, in general, be considered practicable in routine work. For this reason a final section is devoted to a discussion of attempts to 'calibrate' the results from conventional techniques in terms of the more fundamental parameters of powder characterization.

'*Porous bronze: the effects of some powder characteristics on the pressing and sintering properties*', by A. E. S. Rowley (Bound Brook Bearings, Ltd, Lichfield, Staffs). The various tests usually applied to powders for the manufacture of porous bronze are listed. Stress is laid on the importance of consistency of materials. Variations in the important properties of each of the metallic and non-metallic ingredients, and their effect on pressing and sintering behaviour, are discussed. The conclusion reached is that a compromise on powder properties must be accepted in order to achieve economic production.

"*The pressing and sintering properties of iron powders*', by G. Zapf (Sintermetallwerk Krebsöge GmbH, Krebsöge/Rhld, Germany). Some 20 different iron powders are available in Europe for the manufacture of sintered bearings and structural parts. These powders can be grouped under four headings: reduced, atomized, comminuted, and electrolytic. Details are given of the experience gained in testing these types of powder by the methods in common use in the metal-powder industry.

The influence of the data thus obtained on the processing, in particular the pressing and sintering conditions, of iron powders is discussed in detail. Consideration is given to the way in which the properties of the powders affect their sinterability, the pressing operation and tool design, and also the physical characteristics of the finished product.

'*Some problems in the powder metallurgy of titanium*', by S. E. Rogers (The General Electric Co. Ltd, Wembley) An investigation is described of problems encountered in the conventional powder metallurgy of titanium, with particular reference to the pressing and sintering characteristics of titanium and titanium hydride powders and to sources of contamination. It is concluded that, for success to be achieved in the production of fully dense sintered material by the present method without incurring serious contamination, commercial titanium would have to be available as powder conforming to strict purity requirements.

In addition to the above papers, *Powder Metallurgy no.7* also contains the following:

'*The forming of hollow shapes in beryllium by loose sintering and hot processing*', by A. J. Martin, R. A. Knight, and G. C. Ellis (Atomic Weapons Research Establishment, Aldermaston, Berks). Two methods for forming shaped bodies in beryllium by powder metallurgy are described and compared. The requirements for uniform densification during hot pressing are discussed, and it is concluded that a double-pressing method is essential if thin-walled hemispherical shapes are required.

'*Titanium–aluminium–manganese alloys prepared by powder-metallurgical techniques*', by M. F. Grimwade (The General Electric Co. Ltd, Wembley). The preparation of titanium hydride powder and the method of adding aluminium and manganese are described. Sintered materials had poor ductility and this is attributed to the presence of an acicular structure. The tensile strength and ductility of sintered and forged alloys, in which the acicular structure is destroyed, were as good as, and in some cases superior to, those of the equivalent conventional cast and wrought alloy. Both the sintered and the sintered and forged material exhibited good creep properties at 200° and 400°C. Attempts to destroy the acicular structure of the sintered alloy by heat-treatment were unsuccessful.

'*A preliminary study of the reactions between tungsten carbide and tungsten carbide – 6% cobalt powders and wet and dry hydrogen*', by G. E. Spriggs (Hard Metal Tools Ltd, Coventry) The apparent activation energy for the following reactions has been determined by measuring the amount of carbon removed from samples of powder heated to various temperatures in an atmosphere of either dry or wet hydrogen:

*Dry hydrogen:* (a) 'as carburized' tungsten carbide: no reaction up to 900°C; (b) water-milled tungsten carbide: 8·38 kcal/mole over the range 600–900°C; (c) water-milled tungsten carbide + 6% cobalt: complex reaction over the range 600–900°C.

*Wet hydrogen:* (a) 'as carburized' tungsten carbide: 58·1 kcal/mole over the range 800–900°C; (b) water-milled tungsten carbide: 34·8 kcal/mole over the range 700–900°C; (c) water-milled tungsten carbide + 6% cobalt: 38·4 kcal/mole over the range 825–900°C; 7·38 kcal/mole over the range 600–800°C.

It has been shown that ball-milling in water changes both the physical and chemical properties of tungsten carbide powder. These changes are discussed in relation to the marked differences in reaction rates. A number of possible reasons for these differences are given.

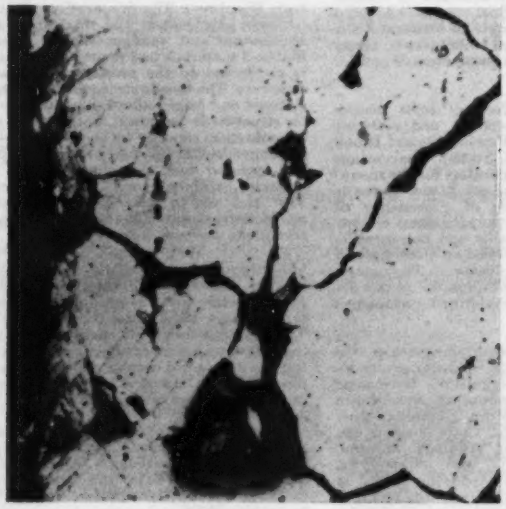
*Letter to the editor*

## Effects of diffusion on corrosion of metals by fused salts

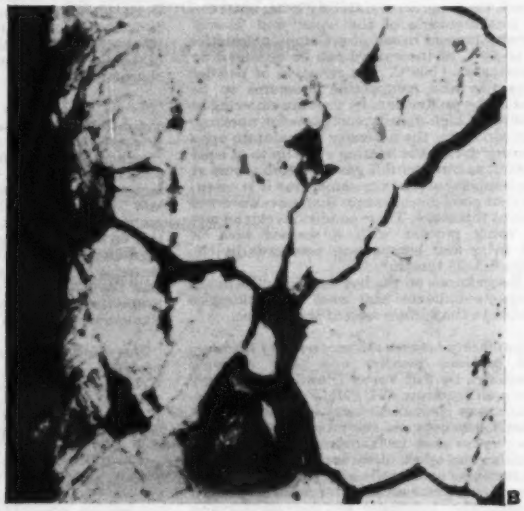
THE DESCRIPTION of an experiment on the corrosion of 18–8 stainless steel by the fused NaCl–KCl mixture recalled a similar experiment of our own with the same type of steel and the ternary eutectic $MgCl_2$/NaCl/KCl in the presence of air. In our case, however, the temperature used was 550°C. After 161 h the specimen was found to be suffering from considerable intergranular attack but there was no evidence that this was a diffusion effect (Figs. *A–C*). No doubt the lower temperature accounts for this as the diffusion rate would be far slower at 550°C than at 800°C. There was, however, a certain amount of discontinuity about the observed attack which was attributed to the unavoidable fact that attack proceeds in three dimensions whereas one can only view two at a time.

Our experience with high-nickel alloys is identical with that of the authors. An Inconel thermal convection loop which contained a fused NaF–LiF–$UF_4$ mixture showed numerous voids, due to preferential diffusion out of Cr, after 891 h at 800°C (Fig. *D*).

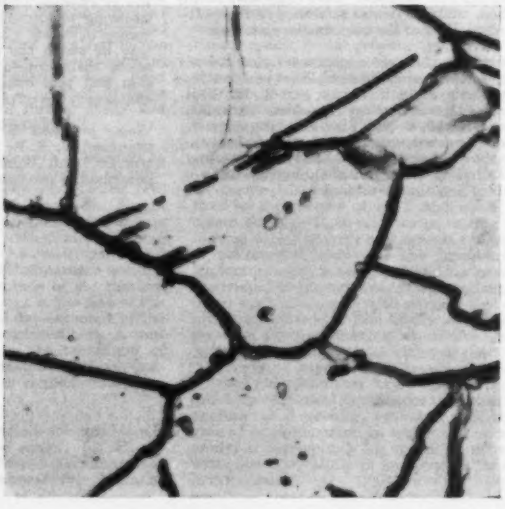
C. EDELEANU *et al.*: *JISI*, 1960, **196**, 59–61.



A



B



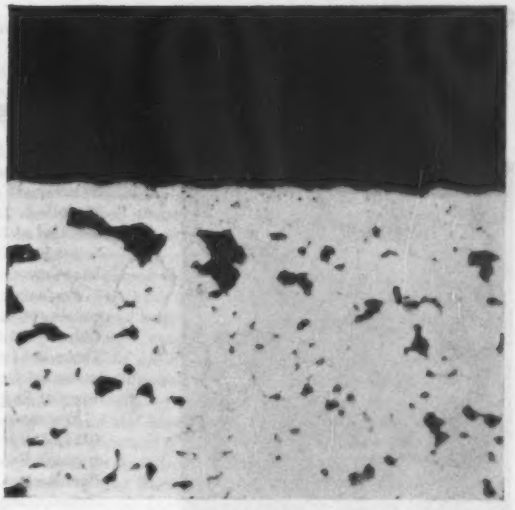
C

**A** *18–8 steel after corrosion by fused chloride salts. Unetched* ×750

**B** *Same field as A after etching 20 s with 20%* $NHO_3$ ×750

**C** *Same specimen as A and B etched with mixed acids* (HCl/$HNO_3$) ×2000

**D** *Inconel after prolonged exposure to fused fluorides, showing voids formed by preferential diffusion of* Cr. *Unetched* ×150



**E** *1%Cr steel showing decarburization at edge due to contact with fused chlorides. Etched with 2% nital* ×150

The probability of decarburization occurring during fused salt corrosion is mentioned in the paper. We have actually had an instance of this, the evidence being shown in Fig.*E*. A pot specimen of 1%Cr steel, containing the $MgCl_2$/NaCl/KCl eutectic, was being run at 550°C when a controller failure occurred, allowing the temperature to rise to 850°C. The last 40 h of the run were at this temperature, therefore, and when examined a decarburized zone about 0·001in deep was found at the inner surface. None of the runs at 550°C caused decarburization.

R. Bricknell

*Materials Group*
*Hawker Siddeley Nuclear Power Co. Ltd,*
*Langley, Bucks.*

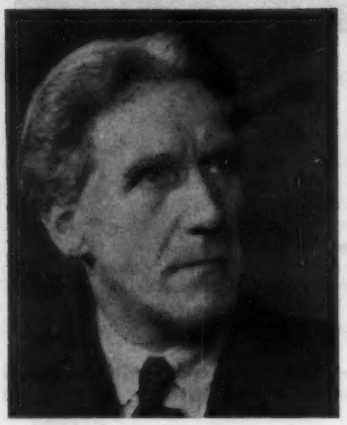
## *Steels for reactor pressure circuits*

*Special Report 69*, which is to be published later this month, contains the 26 papers and six discussion sessions of the symposium on steels for reactor pressure circuits, which was organized by The Iron and Steel Institute for the British Nuclear Energy Conference, and took place in London at the end of last year. Sir Leonard Owen's introductory address (which will be reprinted in the September issue of the *Journal*) is followed by papers and discussions in five general groups: high-temperature properties, corrosion, fabrication aspects, irradiation effects, and steels for future reactors, and the report ends with a general discussion.

In octavo format, with 587 pages of text and extensive illustrations in line and tone, the report is priced at 65*s*. (postage included) and is available from the Secretary of The Iron and Steel Institute.

## OBITUARY

# Professor J. H. Andrew



*The death occurred on 5 May of Emeritus Professor John Harold Andrew, D.SC., Honorary Vice-President of The Iron and Steel Institute and Bessemer Gold Medallist, 1949. Born in Ashton-under-Lyne in 1887, Professor Andrew was educated at Bickerton House School, Birkdale, and Manchester University, where he graduated in chemistry in 1907. He was later appointed a research fellow and demonstrator, and a Dalton scholar, and in 1915 he was awarded his D.SC.*

*Professor Andrew's first appointment outside the university was as head of the metallurgical research department of Sir W. G. Armstrong Whitworth and Co. Ltd, a post he resigned in 1920 to become Professor of Metallurgy at the Royal Technical College, Glasgow, succeeding the late Dr C. H. Desch. In 1932 he also succeeded Dr Desch as Professor of Metallurgy and Dean of the Faculty of Metallurgy at Sheffield University.*

*Professor Andrew had been a Member of The Iron and Steel Institute since 1911, and a Member of Council since 1941. He was a Founder Fellow and an original Vice-President of The Institution of Metallurgists, and he was a Vice-President of The Institute of Metals in 1938–41. He was an active member of the Heterogeneity of Steel Ingots Committee and of several other of the Joint Research committees of The Iron and Steel Institute and the British Iron and Steel Federation. For a time he represented the Institute on the general board of the National Physical Laboratory.*

*Professor Andrew was closely associated with the foundation of BISRA and served on the first Council set up in 1944. He remained one of its most active members until his retirement. He was the first chairman of the Steel Castings Divisional Panel of BISRA (now the British Steel Castings Research Association), and took a leading part in introducing co-operative research into that industry. He was host professor to the research team which worked in his laboratory and which was the nucleus of the Sheffield Group of BISRA. Most of the early BISRA work on automatic gauge control was carried out in his laboratory.*

*The Bessemer Gold Medal was awarded to Professor Andrew in 1949 in recognition of his distinguished services to metallurgy and the iron and steel industry, with special reference to the valuable research work he had conducted, and in acknowledgment of his services to metallurgical education. At the end of the following year ill health forced him to retire from the chair of metallurgy at Sheffield. Since then he and his wife had lived in Llandudno.*

*Professor Andrew was an outstanding metallurgist, teacher, and administrator. He published a considerable number of technical papers, many of them jointly with members of his department and research students which exemplified his sense of loyalty and co-operation. His fertile mind, unorthodox viewpoints, and continuing encouragement are remembered by those who studied under him at Glasgow and Sheffield. Shortly after his retirement a group of Sheffield steel firms established the J. H. Andrew Senior Research Fellowship tenable at his former department, where a laboratory has been named after him.*

*Professor Andrew's wife died earlier this year. They had no children.*

# Professor Dr Ing. Traian Tr. Negrescu

*Traian Tr. Negrescu died on 23 December 1960. He was the founder of the Rumanian school of metallurgy and was one of the most representative figures of Rumanian science and technology.*

*Born in 1900 he completed his grammar school course during the First World War as a refugee in Jassy where he later studied at the mathematical faculty of the university. He obtained a scholarship to the Civil Engineering Institute in Bucharest which later became the Bucharest Polytechnic. Here in 1922, Negrescu obtained his degree as a mining and metallurgical engineer and then became an assistant lecturer at the Polytechnic. In 1924 he went abroad on a grant to specialize and after a period in several French works, he began his studies for the doctorate at the Sorbonne under Professor G. Urbain where, in 1927, he presented his doctoral thesis 'Experimental investigations into quantitative spectral analysis of metallic alloys'. In this thesis, the importance of which is still recognized today, Negrescu laid the foundations of the quantitative spectrography of metallic alloys. He also collaborated with the Swedish scientists, C. Benedicks and A. Westgren, in solving the problem of the composition and structure of chromium carbides in alloy steels, studies which were published at the time in Sweden and in England.*

*Back in Rumania, in 1927, he became reader in metallurgy at the Bucharest Polytechnic where he was to teach the metallurgical disciplines: ore preparation metallurgical machines, non-ferrous, ferrous, and physical metallurgy, for which he prepared and edited the first definitive material. In 1934 he became professor of metallurgy and after the advent of the 'popular' Government, which encouraged scientific research, Negrescu's activity reached new high levels. He created and equipped the metallurgical laboratory at the Bucharest Polytechnic Institute which has become the focus of all Rumanian metallurgical research.*

*In 33 years Negrescu had raised a generation of mining and metallurgical engineers, industrial chemists, and also mechanics who later became metallurgists, who today make up an important proportion of the Rumanian industrial cadres. His lectures were distinguished by their clarity, logical depth of ideas, and by the beauty of his language and will always be remembered by those who heard them.*

*He directed scientific research with his collaborators for the doctorate degree of the Bucharest Polytechnic Institute and conferred the first such degree on the American Professor J. W. Krook of Stanford University, in spectrography.*

*In addition to these activities he undertook fundamental research on equilibria in liquid slags regarding their desulphurization potential in the blast-furnace and their deoxidizing potential in refining furnaces, which was published by the Rumanian Academy of Science and also by the Academy of Science in Moscow. Lately he had studied the modifications of iron during heating in order to establish on this foundation the causes of embrittlement of iron and its alloys.*

*Negrescu became Dean of the Faculty of Metallurgy and Pro-Rector and Rector of the Bucharest Polytechnic Institute. A first-class technical organizer he became Director General at the Ministry of Industry and Trade and of a number of metallurgical works. He was also Director of the Mining and Metallurgical Section of the National Institute of Technological Research, and chief of the section of the Institutes of Physics and Applied Mechanics of the Rumanian Academy of Science.*

*In 1955 his scientific, technical, and teaching merits were recognized by his election as a member of the Rumanian Academy of Science and the Order of Labour was conferred on him by the Rumanian People's Republic.*

*In this capacity, he participated in the foundation of the Centre for Metallurgical Research which he directed in his capacity as President of the Scientific Council. His interest in practical metallurgy led to the founding of 'Studii si Cercetari de Metalurgie' and 'Revue Roumaine de Métallurgie', both now in their fifth years of publication. Through his connexions with scientists abroad he was successful in arranging an exchange with over 200 specialized publications from 32 countries.*

*Academician Negrescu was specially interested in the study of the Soviet metallurgical development and had very close connexions with the late Soviet Academician I. P. Bardin, for whom he had a special regard. His premature death is a great loss to Rumanian science technique and teaching.*

# Special Meeting in the USA and Canada

As previously announced, the Council of The Iron and Steel Institute have accepted an invitation from the Metallurgical Society of the American Institute of Mining, Metallurgical, and Petroleum Engineers to hold a Special Meeting in the USA and Canada in **October and November 1961.** The American Society for Metals have also invited Members and their Ladies to attend their Annual Congress and Banquet and the Metals Exposition at Detroit and to visit the Society's new Headquarters at Metals Park, Novelty, near Cleveland, Ohio.

Invitations to visit their works have been received from many companies in the iron and steel industry and from other metallurgical companies and organizations in the USA and Canada. There will be a number of social functions during the meeting.

The programme is as follows:

## SECTION I NEW YORK

**Tuesday, 17 Oct.** Arrive in New York by charter aircraft or RMS *Queen Elizabeth*.

**Wednesday, 18 Oct.** Free in New York.

**Thursday, 19 Oct.** *Morning* Free
*Afternoon* Inaugural session at the new Engineering Societies Building. Address of welcome by the President of the American Institute of Mining, Metallurgical, and Petroleum Engineers (AIME), followed by lecture 'Three centuries of progress in the American iron and steel industry' by Dr James B. Austin.
*Evening* Cocktails and dinner at the Starlight Roof Restaurant, Waldorf-Astoria Hotel, by invitation of United States Steel Corporation.

**Friday, 20 Oct.** MEMBERS
*All day* Visit to Fairless Works of United States Steel Corporation.
LADIES
*Afternoon* Visit to The Cloisters (museum of medieval art), Fort Tryon Park.
MEMBERS AND LADIES
*Evening* Free.

## SECTION II NIAGARA FALLS

**Saturday, 21 Oct.** MEMBERS AND LADIES
*All day* Travel by special train from New York to Buffalo. Transfer from Buffalo to Niagara Falls, Ont., by bus.

**Sunday, 22 Oct.** MEMBERS AND LADIES
*Afternoon* Sightseeing tour of Niagara Falls area, by invitation of Union Carbide Ltd (London), visiting Whirlpool Rapids, Fort Niagara, Fort George, Niagara on the Lake, etc.
*Evening* Buffet supper at Prud'homme Restaurant, St Catherines, Ont., by invitation of Union Carbide Ltd.

**Monday, 23 Oct.** MEMBERS
*All day* Visits to the Research Laboratories of Union Carbide Metals Company, Niagara Falls, NY, and to the Research Laboratories of the Linde Company, Tonawanda, NY.
LADIES
*All day* Visit to Toronto by invitation of Union Carbide Canada Ltd.
MEMBERS AND LADIES
*Evening* Cocktails and dinner at the Sheraton-Brock Hotel, Niagara Falls, Ont., by invitation of Union Carbide Corporation.

**Tuesday, 24 Oct.** MEMBERS
*All day* Visit to iron and steelworks at Hamilton, Ont., with lunch; the plant of Dominion Foundry and Steel Co. Ltd will be visited in the morning and that of the Steel Company of Canada Ltd in the afternoon.
LADIES
*All day* Visit to Hamilton area.
MEMBERS AND LADIES
*Evening* Cocktails and dinner at Royal Connaught Hotel, Hamilton, by invitation of the Canadian steel companies.

**Wednesday, 25 Oct.** MEMBERS AND LADIES
Canadian breakfast at the Sheraton-Brock Hotel, Niagara Falls, Ont., by invitation of the Canadian steel companies.
MEMBERS
*Morning* Visit to the works of Atlas Steel Co. Ltd, Welland, Ont.
LADIES
*Morning* Visit to the installations of the Welland Canal.
MEMBERS AND LADIES
Lunch at Rathfon Inn, Port Colborne, Ont., by invitation of the Canadian steel companies.
*Afternoon* Leave for Cleveland or Detroit.

## SECTION IIIA CLEVELAND

**Wednesday, 25 Oct.** MEMBERS AND LADIES
*Evening* Arrive in Cleveland.

**Thursday, 26 Oct.** MEMBERS
*Morning* Visit to *either*
Cleveland iron and steelworks of Republic Steel Corporation *or*
Case Institute of Technology.
*Afternoon* Visit to Research Center of Republic Steel Corporation.
LADIES
*All day* Sightseeing tour of Cleveland area, with lunch at Metals Park, Novelty, by invitation of the American Society for Metals.
MEMBERS AND LADIES
*Evening* Cocktails and dinner at the Statler-Hilton Hotel, Cleveland, by invitation of Republic Steel Corporation.

**Friday, 27 Oct.**

MEMBERS

*All day* Visit to Canton and Massillon works of Republic Steel Corporation. The group will travel by bus to Pittsburgh after the works visits.

LADIES

*Morning* Visit to Cleveland Art Museum.

*Afternoon* Travel by bus to Pittsburgh.

## SECTION IIIB DETROIT

**Wednesday, 25 Oct.**

MEMBERS AND LADIES

*Evening* Arrive in Detroit.

**Thursday, 26 Oct.**

MEMBERS

*Morning* Attend meetings of the American Society for Metals (ASM) and the Metallurgical Society of the American Institute of Mining, Metallurgical, and Petroleum Engineers, and ASM Metals Exposition.

*Afternoon* Visit works of Great Lakes Steel Corporation, Ecorse, Mich.

LADIES

*Afternoon* Sightseeing in Detroit area by arrangement with Ladies' Committee of Detroit Chapter of ASM.

MEMBERS AND LADIES

*Evening* Attend Banquet of American Society for Metals.

**Friday, 27 Oct.**

MEMBERS

*All day* Travel in the morning by air to Cleveland, then by bus to visit the Canton and Massillon works of Republic Steel Corporation. The group will travel by bus to Pittsburgh after the works visits.

LADIES

*Either*

*All day* Travel by bus from Detroit to Pittsburgh.

*Or*

*All day* Visit to automobile plant of Ford Motor Company, museum, and Dearborn village.

*Evening* Fly to Pittsburgh.

## SECTION IV PITTSBURGH

**Friday, 27 Oct.**

MEMBERS AND LADIES

*Evening* Arrive in Pittsburgh.

**Saturday, 28 Oct.**

MEMBERS AND LADIES

*Afternoon* Attend American football game between the University of Pittsburgh and the US Naval Academy.

*Evening* Cocktails, buffet supper, and dancing at the Pittsburgh-Hilton Hotel. The President, Sir Charles Goodeve, will be the host.

**Sunday, 29 Oct.**

MEMBERS AND LADIES

*Afternoon* Attend concert of the Pittsburgh Symphony Orchestra or flower show.

**Monday, 30 Oct.**

MEMBERS

*All day* Visit to Aliquippa works of Jones and Laughlin Steel Corporation.

LADIES

*Afternoon* Sightseeing in Pittsburgh, visiting the University, Heinz Memorial Chapel, etc.

MEMBERS AND LADIES

*Evening* Cocktails and dinner at the Duquesne Club, Pittsburgh, by invitation of the Association of Iron and Steel Engineers.

**Tuesday, 31 Oct.**

MEMBERS

*Either*

*All day* Visit to Research Center, Monroeville, and blast-furnace pilot plant, Universal, Pa., of US Steel Corporation.

*Or*

*Morning* Free or visit to Carnegie Institute of Technology.

*Afternoon* Visit to Homestead Works of US Steel Corporation.

LADIES

*Afternoon* Visit to Rolling Rock Country Club, Ligonier.

**Wednesday, 1 Nov.**

MEMBERS AND LADIES

*Either*

*Morning* Visit to Gulf Research and Development Company Laboratories at Harmarville.

*Afternoon* Fly from Pittsburgh to Washington, DC.

*All day* Travel by bus from Pittsburgh to Washington, with lunch en route.

*Or*

*Morning* Travel by bus or air to Warren, Pa.

*Afternoon* Visit to the steelworks and heavy forges of the National Forge Company, Irvine, Pa.

*Evening* Dinner at the Connewango Country Club by invitation of the National Forge Company. Spend night in motel at Warren, Pa.

**Thursday, 2 Nov.**

MEMBERS AND LADIES (only for those visiting Warren, Pa.)

*Either*

*All day* Travel by bus from Warren to Washington, DC,

*Or*

*Morning* Travel by air from Warren to Washington, DC.

*Afternoon and evening* See Washington programme below.

## SECTION V WASHINGTON

**Wednesday, 1 Nov.**

MEMBERS AND LADIES (except party visiting Warren, Pa.)

*Evening* Arrive in Washington.

**Thursday, 2 Nov.**

MEMBERS AND LADIES

*Afternoon* Sightseeing tour of Washington, no.1, visiting the Capitol, Library of Congress, Supreme Court, and Folger Library.

**Friday, 3 Nov.**

MEMBERS

*All day* Visit to Sparrows Point works of the Bethlehem Steel Company.

LADIES

*Afternoon* Visit to National Art Gallery.

**Saturday, 4 Nov.**

MEMBERS AND LADIES

*Afternoon* Sightseeing tour of Washington, no.2, visiting Lincoln and Jefferson Memorials, Arlington National Cemetery, Marine Monument, etc.

*Evening* Cocktail party in the Rotunda at the British Embassy, by invitation of Mr J. Rennie, C.M.G., HM Commercial Minister, and Mrs Rennie.

**Sunday, 5 Nov.**

MEMBERS AND LADIES

*Afternoon* Visit by bus to Mount Vernon.

**SECTION VI NEW YORK**

**Monday, 6 Nov.** MEMBERS AND LADIES
*Morning* Travel by train from Washington to Philadelphia.
*Afternoon* Sightseeing tour (4 hours) of Philadelphia; then travel by train to New York.

**Tuesday, 7 Nov.** MEMBERS AND LADIES
*All day* Free in New York.

**Wednesday, 8 Nov.** MEMBERS AND LADIES
Return to UK by RMS *Queen Mary* (morning departure) or BOAC Britannia charter aircraft (late evening departure).

**End of Meeting**

**EXTENSION I MIDDLETOWN AND CHICAGO**

**Sunday, 5 Nov.** MEMBERS AND LADIES
*Evening* Travel by air from Washington, DC, to Cincinnati, Ohio.

**Monday, 6 Nov.** MEMBERS
*All day* Visit to Middletown works of Armco Steel Corporation.

MEMBERS AND LADIES
*Evening* Travel by air from Cincinnati to Chicago, Ill.

**Tuesday, 7 Nov.** MEMBERS
*All day* Visit to Indiana Harbor works of Inland Steel Company.

**Wednesday, 8 Nov.** MEMBERS
*All day* Visit to Chicago works of Youngstown Sheet and Tube Company.

MEMBERS AND LADIES
*Evening* Those wishing to return to the UK by the BOAC Britannia charter aircraft fly from Chicago to New York. Evening free for remainder.

**Thursday, 9 Nov.** MEMBERS
*All day* Visit to plant of the Midwest Division of the National Steel Corporation, Valparaiso, Ind.

A suitable programme for Ladies is being arranged.

**End of Extension I**

**EXTENSION II WILLIAMSBURG AND COLONIAL VIRGINIA**

**Sunday, 5 Nov. to Tuesday, 7 Nov.** MEMBERS AND LADIES
Leave Washington, DC, on morning of 5 November, and travel by car through Colonial Virginia, visiting Fredericksburg, Yorktown, Jamestown, Williamsburg, Richmond, Charlottesville, and the Shenandoah National Park. Return to Washington in the early evening of 7 November.

**Wednesday, 8 Nov.** MEMBERS AND LADIES
*Morning* Travel by train from Washington to New York.

**End of Extension II**

# EDUCATION

Universities
Technical colleges
Industry

### Careers in fuel

A booklet 'Careers in fuel', prepared under the authority of the Council of the Institute of Fuel, and recently published, outlines the importance of fuel with particular reference to the UK, and the training of a fuel specialist. The composition of The Institute of Fuel and the available courses in fuel technology are described. The booklet is available from the Secretary, The Institute of Fuel, 18 Devonshire Street, Portland Place, London W1.

### NIFES annual refresher course

The eighth annual refresher course of the National Fuel Efficiency Service is on 'Current practice in fuel efficiency' and will be held at the Clarendon Laboratory, Oxford, from 25 to 29 September. Preliminary programmes and registration forms are now available. There will be seventeen sessions, including three evening periods at Brasenose College, where resident members will be accommodated. The fee for resident members, covering the whole course, meals, and accommodation, is 16 *gns*. The fee for non-resident members, who also will receive meals, is £11.

Besides the main lectures there will be open discussion, and the evening sessions will provide opportunity for informal meeting. A choice of two works visits will be available. Further information may be had from P. Snaith, Eighth Annual Refresher Course, National Industrial Fuel Efficiency Service, Ailsa House, 181 King's Road, Reading. The final date for the return of application forms is 11 September.

### Borough Polytechnic: winter courses

The Borough Polytechnic has announced four courses of special lectures for the winter term 1961–62. They are generally intended for metallurgists, chemists, physicists, and engineers, and are all evening courses.

*Modern developments in non-destructive testing of metals* From 4 October, six lectures, fee 10*s*, various lecturers

*Refractories, their manufacture, properties, and uses* From 6 October, ten lectures, fee £1, lecturer L. Barrett

*Recent advances in semi-conductor metallurgy* From 24 October, six lectures, fee £1, lecturer A. S. Abrahams

*Corrosion and protection of buried metal* From 2 November, six lectures, fee 10*s*, various lecturers.

Further information on these courses may be had from G. Isserlis, B.SC., Division of Metal Science, Borough Polytechnic, London SE1.

### Technical Education Abstracts

The first issue of a new publication, 'Technical Education Abstracts' (quarterly, 2 *gns* a volume), has been published by the National Foundation for Educational Research. The new abstract service is intended for people concerned in further education and training, inside and outside the public educational system. Each entry consists of a summary of about 200 words with full bibliographical details; the abstracts are prepared by specialists in educational fields. The number of journals scanned is large, and the abstracts are of a very useful kind; classification by subject is clear and facilitates reference. Further information may be had from The National Foundation for Educational Research in England and Wales, 79 Wimpole Street, London W1.

### O for Oxygen

To mark its 75th anniversary BOC has made a film *O for Oxygen*, which illustrates the growth of the present industry from Priestley's discovery of oxygen in 1774. It is in Eastmancolor, runs for 23 min, and was among the 15 British entries for the Second International Festival of Industrial Films at Turin in June. Copies in 16 mm and 35 mm will soon be available on free loan from BOC to schools, colleges, and similar organizations.

# NEWS | *Announcements and News of Science and Industry*

## THE IRON AND STEEL INSTITUTE

### Special Meeting in the USA and Canada

The revised programme for this meeting is given on pp.420–422 of this issue.

### Autumn General Meeting 1961

The Institute's Autumn General Meeting and a meeting of the Iron and Steel Engineers Group will be held in London from **Wednesday 29 November** to **Friday 1 December 1961.** Papers for discussion will include 'The future of ironmaking in the blast-furnace' and 'Energy balance in iron and steelworks' as well as papers on scientific subjects, including physical metallurgy and thermodynamics. Full details will be published later in the *Journal*.

### Institute Meetings, 1962

*Annual General Meeting* 2 and 3 May
*Autumn General Meeting* 28 and 29 November
*Special Meeting in Germany* By invitation of the Verein deutscher Eisenhüttenleute the Institute will hold a special meeting in Düsseldorf from 2 to 8 July 1962 with short excursions before and after these dates. Further details will be published as soon as possible.

### Birthday Honours

*Knight* Mr A. G. B. Owen, C.B.E. (*Member*), chairman and joint managing director of Rubery, Owen and Co. Ltd.
*C.B.E.* Dr L. F. C. Northcott (*Member*), principal superintendent and head of materials division, Armament Research and Development Establishment.
*C.B.E.* Mr R. G. C. Parry-Okeden (*Member*), chairman and managing director of John Lysaght (Australia) Ltd.

### Beilby Medal and Prize 1961

The administrators of the Sir George Beilby Memorial Fund, representing the Royal Institute of Chemistry, the Society of Chemical Industry, and The Institute of Metals, have announced the awards from the fund for 1961. These consist of the newly instituted gold medal and a prize of 100 *gns*, and they have been made to the following:
C. Edeleanu, M.A., PH.D. (*Member*) in recognition of his work on the corrosion of metals and alloys, with special reference to the development of the potentiostat technique and its applications to the study of practical problems, and on the characteristics of corrosion reactions in fused salts.
Professor J. Nutting, M.A., B.SC., PH.D., F.I.M. (*Honorary Member of Council*) in recognition of his work in physical metallurgy especially in the application of the electron microscope to the study of the relationship between microstructure and mechanical properties of metals and alloys, and to the investigation of phase changes and dislocation interactions.

## NEWS OF MEMBERS

Dr **C. S. Ball,** at present superintendent of research, steel division, has been appointed research controller of The Steel Company of Wales Ltd.

Mr **W. E. Bardgett** retired from the position of research manager in the research and development department of The United Steel Companies Limited on 1 July 1961, but remains with the department as a consultant.

Mr **F. H. Brooks** has been appointed to the board of Hadfields Ltd.

Mr **R. D. Butler** has joined the Pressed Steel Company Ltd, Cowley, as a metallurgist.

Mr **A. B. Carter** has joined the engineering division of the British Oxygen Company as a metallurgist.

Mr **H. C. Challiner** has been appointed local director of Lysaght's Scunthorpe Works of GKN Steel Company Ltd.

Mr **G. E. Davies** is leaving BISRA to join the Iron and Steel Board.

Mr **W. H. Day** has been appointed to the board of The Wellman Smith Owen Engineering Corporation Ltd as commercial director, and has relinquished his position as secretary.

Mr **A. T. Easterbrook** has been appointed general manager of the furnace building and contracting department of The Wellman Smith Owen Engineering Corporation Ltd.

Dr **A. E. El-Mehairy** will resume his post as lecturer in metallurgy, Cairo University, Egypt, at the beginning of September. He has finished his work on the reduction of iron ore particles in fixed beds at the Carnegie Institute of Technology, Pittsburgh, USA.

Sir **Lincoln Evans** has been re-appointed deputy chairman of the Iron and Steel Board.

Mr **O. F. Grazebrook,** J.P., following his retirement from the board of the British Rollmakers Corporation Ltd, has been appointed a joint honorary president of the Corporation.

Dr **E. Gregory** has resigned from the chairmanship of the research committee of the British Steel Castings Research Association.

Mr **G. T. Harris** has been appointed assistant managing director of Jessop-Saville Ltd.

Dr **K. J. Irvine** became metallurgical research manager of The United Steel Companies Limited on 1 July 1961.

Mr **M. C. Lloyd** has been appointed chairman of the research committee of the British Steel Castings Research Association.

Mr **R. P. Mackay** has been appointed superintendent, steel plants, of the steel division of The Steel Company of Wales Ltd.

Mr **D. R. W. Price** is now research investigator at Bradley and Foster Ltd, Darlaston.

Lord **Riverdale** has been appointed to the board of Hadfields Ltd.

Mr **N. Robinson** has joined the welding research department of Hadfields Ltd.

Professor **Merrill A. Scheil,** director of metallurgical research of the A. O. Smith Corporation, Milwaukee, USA, has received a citation from the University of Wisconsin in recognition of his contributions to metallurgical engineering as an engineer, author, and administrator.

Sir **Robert Shone,** C.B.E. (*Honorary Member of Council*) has been re-appointed executive member of the Iron and Steel Board.

Mr **C. D. Wattleworth** has been appointed assistant managing director (technical) of The Wellman Smith Owen Engineering Corporation Ltd.

Mr **T. B. Wilson** has joined Atomic Power Constructions Ltd as senior metallographer.

Mr **C. E. Wrangham** has retired from the boards of Davy-Ashmore Ltd and its subsidiaries.

### Obituary

**Reginald Ewart Davies** (*elected 1947*), of Port Talbot, on 2 January.

**William Danily Johnson** (*Life Member, elected 1909*), of Lane End, Buglawton, Congleton, on 12 June.

**James Tennent,** D.L., J.P., (*elected 1923*), of Coatbridge, Lanarkshire, in May 1961.

**Eric James Whitehead** (*elected 1937*), of Derby, on 13 May.

## BRITISH IRON AND STEEL RESEARCH ASSOCIATION

### New President

Mr H. F. Spencer (*Member*), managing director of Richard Thomas and Baldwins Ltd, has accepted appointment as President of BISRA in succession to the late Sir Charles Bruce-Gardner.

### Conference: hydrogen in steel

The Metallurgy Division of BISRA is to hold a conference on hydrogen in steel at Harrogate from 11 to 13 October 1961. Aspects to be discussed include: removal of hydrogen from liquid and solid steel, diffusion and solubility of hydrogen in steel, the effect of hydrogen on the properties of ultra-high-tensile steels, and hydrogen in weld metal. Full details and application forms are available from the Technical Secretary, Metallurgy Division, BISRA, 11 Park Lane, London W1.

### Control engineering section

A new section has been created within the Plant Engineering and Energy Division of BISRA, to centralize the Association's research into control engineering. The new section replaces the Electrical Engineering Section, a branch of the Plant Engineering and Energy Division which was formed to carry out research into the electrical equipment used in steelworks. During recent years the research of this section has been increasingly concerned with automatic control systems, and since another section of the division has carried out research on hydraulic control systems and the basic theory of control applies to both, the formation of a section covering all aspects of control engineering offered certain advantages. Mr J. P. Clyne, M.A., who joined BISRA from the Sperry Gyroscope Co. Ltd, has been appointed head of the new section.

### Sheffield Open Days

Over 1200 people, mostly from the iron and steel and allied industries, were visitors at the Sheffield laboratories of BISRA when on 15 and 16 June the Sheffield divisions, dealing with steelmaking, mechanical working, and metallurgy, held Open Days for the second time since the official opening of the Hoyle Street premises in 1953. Members of the various research groups, some from other divisions, were on hand at 15 different displays to answer questions or to explain the significance of the work that is currently going on. The Steelmaking Division's work on continuous casting was exemplified in a demonstration of ingot casting. A method for the rapid annealing of tinplate developed in the Association's Swansea laboratories included a new 'Elphal' process for the aluminium coating of steel strip. Spray refining and the vacuum degassing of molten steel were featured in other displays. The Metallurgy Division's displays included a ciné film, probably the first anywhere, of the movement of domains under the influence of magnetic fields. The operational research activities of BISRA were illustrated by diagrammatic analyses of the work the Association has carried out effectively with member firms. The Corrosion Advice Bureau and the Information Services were also represented.

The organization of the display of work was admirable, and the Association had clearly put a lot of thought into making their visitors as comfortable as possible.

### Annual Report

*BISRA Annual Report 1960* outlines the main lines of development in all branches of BISRA's research and development work, including work on the use of computers that was carried out last year, and includes also the general report of council and the annual accounts. It is available from Mr D. U. Hunt, The British Iron and Steel Research Association, 11 Park Lane, London W1.

## IRON AND STEEL BOARD

### Present membership

*Chairman* Sir Cyril Musgrave, K.C.B.
*Deputy Chairman* Sir Lincoln Evans, C.B.E.
*Executive Member* Sir Robert Shone, C.B.E.
Sir Charles Connell, Mr Harry Douglass, Sir Kenneth Hague, Mr N. C. Macdiarmid, Mr A. J. Peech, Sir Henry Spurrier, Mr A. G. Stewart, Sir Thomas Williamson, C.B.E., J.P., and Sir Alan Wilson, F.R.S.

## THE INSTITUTION OF METALLURGISTS

### Council elections

At the annual general meeting of the Institution the following elections for the session 1961–62 were made: *President* Dr N. P. Allen, *Senior Vice-President* Dr E. G. West, *Vice-Presidents* F. Dickinson and Dr L. Northcott, *Hon. Treasurer* L. W. Derry, *Members of Council*, H. Morrogh, S. S. Smith, and Dr J. C. Wright.

## THE INSTITUTE OF PHYSICS AND THE PHYSICAL SOCIETY

### Autumn conference

The autumn conference of the X-ray analysis group of the Institute and Society on 'Imperfections in crystals' will be held on 17 and 18 November 1961 at the Institution of Mechanical Engineers in London. The three sessions will be devoted to the nature of imperfections and associated diffraction effects, experimental methods for the study of imperfections, and their influence on the physical properties of crystals. Among the invited speakers will be Dr P. B. Hirsch and Professor F. C. Frank, O.B.E.

Enquiries about the programme should be addressed to Dr G. S. Parry, Department of Chemical Engineering, Imperial College of Science and Technology, London SW7; and about attendance to the Administration Assistant, The Institute of Physics and The Physical Society, 47 Belgrave Square, London SW1.

## THE INSTITUTION OF MINING AND METALLURGY

### President 1961–62

At the annual general meeting of The Institution of Mining and Metallurgy, Mr A. R. O. Williams, O.B.E., A.R.S.M., B.SC., was inducted into the chair as president during the session 1961–62. Mr Williams is a managing director of Consolidated Goldfields of South Africa Ltd and chairman of the South West Africa Co. Ltd.

### Awards

The council of the Institution has announced the following awards:

*Gold Medal of The Institution of Mining and Metallurgy for 1960* The Rt Hon. Lord Baillieu, K.B.E., C.M.G.
*'The Consolidated Gold Fields of South Africa Ltd' Gold Medal for the session 1959–60* R. N. Pryor
*'The Consolidated Gold Fields of South Africa Ltd' Premium of Forty Guineas* M. L. Fitzgerald, M.I.M.M.
*The 'Arthur Claudet' Student's Prize* P. D. R. Maltby, B.SC.
*The 'William Frecheville' Student's Prize* A. G. Darnley, B.A., PH.D.

## CONTRIBUTORS TO THE JOURNAL

| | |
|---|---|
| *R. C. Benson* | *R. J. H. Hunt* |
| *M. C. Harrison* | *P. Truscott* |
| *D. G. Owen* | *R. A. Sharma* |
| | *D. W. Mitchell* |

**R. C. Benson,** M.C., B.ENG.—Special director, The Darlington Forge Ltd.
Ronald Carey Benson was born in Sheffield and educated at Oundle. He read for a degree in engineering from 1912 to 1914 at Sheffield University while taking the Vickers 'sandwich' course. He took a degree in 1914 with a first in mechanical engineering.

He was commissioned in the 3rd West Riding Royal Field Artillery T.F. in 1912, and was mobilized in 1914. He went to France in April 1915 with this unit; the same year he was mentioned in despatches and awarded a M.C. In 1917 he was wounded, and on recovery was selected for the Long Course, Woolwich. He passed the first half of the P.A.C. Course in 1918, top in mechanical engineering, but was then seconded to the Ministry of Munitions to fill a vacancy as assistant to the Ballistic Officer, Woolwich.

On demobilization in 1919 he was appointed assistant forge manager to the late H. Lodge at Vickers Works, Sheffield. In charge of the forging presses, he was responsible for post-war developments in heavy forging including improved methods of forging turbine discs, a simplified method of extracting mandrels from hollow forgings, and the forging of pressure vessels and boiler drums with closed or bottled ends, the earliest concerning a contract just after the first World War for 11 vessels ordered by Russia for oil cracking.

In 1931 he was appointed forge manager, at Vickers and Cammell's forges of the newly formed English Steel Corporation when work started on the changeover from large steam cranes and presses powered by steam-driven pumps to the electro-hydraulic presses of the 7000-ton press shop and the new medium forge at Vickers River Don works.

In 1936, when a very rapid expansion of production for rearmament was needed, he became forge manager at the Darlington Forge of the English Steel Corporation; by 1939 the capacity of this forge had increased between 300% and 400%. In particular the production of forged propeller brackets far exceeded that of any other forge in the country, or indeed probably in the world, the peak being over 100 such brackets in one year.

In 1953 he was appointed special director, Darlington Forge; over the period 1954–6 he was chairman, Forging Committee, BISRA; and during 1958–60 a member of the Mechanical Working Division Panel, BISRA. Between 1951 and 1958 he visited most forge plants of note in Europe, USA, and Canada.

In 1957–8 he wrote a series of articles on 'Forging in the past', describing changes in such work from the early days of the water-driven hammers to the introduction of the first forging manipulator at Vickers Works in 1898.

At present he is much occupied in developing methods of forging profiled reinforcing rings for the heat exchangers and reactor shells of nuclear power plants.

**R. J. H. Hunt,** ASSOC. ENG., M.I.P.E.—Forge superintendent, English Steel Corporation.
R. J. H. Hunt was educated at Firth Park Grammar School. He joined Vickers-Armstrong Ltd (later the English Steel Corporation Ltd) in 1928 and trained as a draughtsman. He studied in the evenings at Sheffield University and obtained the Higher National Certificate and an Associateship in Mechanical Engineering. Owing to an interest in forging he transferred to the forge department in 1933, at first as an estimator and then as assistant to Mr Benson, at that time forge manager. He was forge production manager from 1940 to 1948 when he joined Rotherham Forge and Rolling Mills Corporation Ltd. He returned to English Steel Corporation Ltd in 1952 and was appointed forge superintendent in 1959.

His interest in oxy-cutting has been largely responsible for its development and its increasing use in the speedier production of heavy forgings. He is a member of the Institute of Production Engineers, and of the BISRA Forging Committee, and was appointed to the Engineering Committee of The Iron and Steel Institute in 1960.

**M. C. Harrison,** A.I.M.—Manager, VLN steel plant, The Steel Company of Wales Limited.
M. C. Harrison was educated at Blundell's School, Tiverton, Devon. On leaving he joined Messrs Baldwins Limited at Panteg as a trainee in the melting shop, foundry, and drawing office. He transferred to the Port Talbot melting shop of Guest Keen and Baldwins Ltd, as an assistant sample passer, becoming sample passer, assistant manager, and manager. Appointed as manager of the oxygen/steam converter plant in 1958, about 18 months before the plant began production, he was responsible for its manning, commissioning, and operation.

**P. Truscott,** B.SC.—Assistant manager, VLN steel plant, The Steel Company of Wales Limited.
P. Truscott graduated in metallurgy from the University College of Wales, Swansea, in 1948. He worked at development on the chromizing process with the New Chrome Metal Company Ltd, from 1948 to 1952, and then carried out steelplant research at Colvilles Ltd, from 1952 to 1955. In 1955 he joined The Steel Company of Wales Ltd, becoming senior research metallurgist for mills and melting shops before taking up his present appointment.

**D. G. Owen,** B.A.—Head of Operational Research and Cybernetics Department, The United Steel Companies Ltd.
Mr Owen studied mathematics at Gonville and

Caius College, Cambridge, and in 1942 joined the operational research section at RAF Bomber Command Headquarters. After the war he was one of the earliest members of the newly formed Operational Research Department at BISRA, and he later became head of the Computer Applications Section. In 1956 he moved to The United Steel Companies Ltd as computer applications manager in their department of operational research and cybernetics, and has recently been appointed head of that department. He is the author of a number of papers on the applications of computers to industry, among which is an explanatory booklet entitled 'Computers and steel' published by BISRA.

**R. A. Sharma,** B.SC., M.SC.—Research trainee, Nuffield Research Group in Extraction Metallurgy, Imperial College of Science and Technology, London.

R. A. Sharma graduated from Banaras Hindu University in 1952 with a M.SC. From 1953 he worked at the National Metallurgical Laboratory, Jamshedpur, India, and was a senior scientific officer before he came to the UK in 1959 under the Colombo Plan. He has published a number of research and technical papers relating to extraction metallurgy.

**D. W. Mitchell,** B.SC., A.B.S.M., A.M.I.M.M.—Development Department, The Park Gate Iron and Steel Company Limited.

Dennis Walter Mitchell was born in 1927 and graduated from the Royal School of Mines in 1949. After a year's post-graduate field work in Ontario and a teaching appointment at the University of Toronto, he spent a further four years in Eastern Canada, first as metallurgist with the Kilborn Engineering Company of Toronto and later as research engineer for Johnson's Co. Ltd in Quebec. In 1955 he joined the research and development department of The United Steel Companies Ltd where he was employed as senior assistant (minerals section). He left in January of this year to join the Development Department of the Park Gate Iron and Steel Company Ltd.

## NEWS OF SCIENCE AND INDUSTRY

### Jernkontoret award

Jernkontoret, the Swedish ironmasters' association, has awarded its gold medal to Mr Rutger von Seth, of Åkers Styckebruk, in recognition of his important scientific work, especially on surface decarburization of steel, and of the expansion of Åkers Styckebruk under his leadership since 1942.

### Changes at United Steels

Mr W. Jackson (*member*), works manager (steel) at Appleby-Frodingham, is being attached to the staff of Steel, Peech and Tozer for an extended period in connexion with current steelmaking activities there. Under an interim arrangement at Appleby-Frodingham, Mr R. Wogin, (*member*), assistant works manager (steel), is to concentrate upon rolling mill matters, responsible to the general works manager, Mr G. D. Elliott (*member*). Mr R. Johnson (*member*), melting shops manager, is to report directly to the general works manager.

### Appointments

*Hilger and Watts Ltd* announce that Mr A. H. Campbell, M.A., who has been a director of the company since 1951 and general manager since 1954, has been appointed joint managing director with Mr G. A. Whipple, M.A.

*International Computers and Tabulators Ltd* announce that Sir Edward Playfair, K.C.B., formerly permanent secretary to the Ministry of Defence, has been appointed chairman of the company.

### Vacuum casting at Steel Peech

Commercial quantities of vacuum-cast steel are now being produced from a 7-ton electric arc furnace at Steel, Peech and Tozer. The company plans to replace its existing OH capacity by six 110-ton electric arc furnaces so that much greater tonnages may be vacuum-cast.

### Czechs make high-Al alloy steel

The national institute of materials and technology in Prague has discovered a method of alloying steel with a high proportion (30%) of aluminium. The new alloy is called 'Pyroferral' and a typical composition contains, in addition to the aluminium, 1%C, 0·7%Mn, and 0·5%Si. Heat- and corrosion-resisting properties are said to be as high as those of the best Cr–Ni steels, but the cost is much lower.

### Soviet Orders for SCOW

The Soviet car industry has placed a second order with The Steel Company of Wales for 10 000 tons of cold reduced sheets. In addition, it is reported that the company has arranged to roll 38 000 tons of hot-rolled coil from a Soviet steelworks for return shipment in sheet.

Plans have recently been announced for the construction of a new port between Port Talbot and Porthcawl to take ore carriers of up to 60 000 tons. Estimated cost of the project is £10 m.

### Wrecking crane for Canada

A 120-ton railroad wrecking crane of 300 000-lb lifting capacity recently completed by Cowans, Sheldon and Co. Ltd of Carlisle, will soon be in service in Canada, working with its predecessor (500 000 lb) on a 190-mile railway from an iron ore mine in Northern Quebec to a new harbour on the St Lawrence estuary. The railway is being built by the Quebec-Cartier Mining Company, which is owned by US Steel, and it was from this company that the British company received an order in January 1960 for two large diesel railroad wrecking cranes. The cranes are the only items of major equipment in this project that were ordered outside the American continent. Both are designed to work in the difficult Arctic conditions of the region, in temperatures down to −60°F; the first was designed, built, and tested in nine months so that it could be delivered at Port Cartier in November 1960 before the St Lawrence Seaway froze up. Like its predecessor, the smaller crane is of diesel-hydraulic design, mounted on a six-axle, double-bogie carriage; engine and torque converter were supplied by Rolls Royce, air brakes and controls by Westinghouse, and the cast steel bogies and centre couplers by English Steel Corporation. The crane's main function will be to re-rail locomotives and rolling stock. Full details will be supplied on enquiry to the managing director, Cowans, Sheldon and Co. Ltd, Carlisle, to whom requests for the loan of a short film of the first crane's construction may also be made.

Cowans, Sheldon have recently received an order from The Steel Company of Wales for an 85-ton diesel crane, which will probably be the largest in the UK; the largest at present are the 75-ton British Railways cranes.

### 'Fair Oriana'

The United Steel Company's latest film, *Fair Oriana* is a traditional documentary of great interest. From opening aerial shots of the 42 000-ton P & O vessel on her sea trials, the film cuts back to the factories in which some of the sections, plates, tubes, and forgings used in her construction were made. Unexpected angle shots avoid the clichés of filming a large construction, and the natural sounds of shipyard and steelworks are used effectively. The film ends with the launching and start of the maiden voyage to Australia of *TSS Oriana*, the largest passenger vessel to be built in England.

Produced by A. Frank Bundy, *Fair Oriana* is in colour, 35 mm, running time 28 min. It is available on loan from The United Steel Companies Ltd, The Mount, Broomhill, Sheffield.

### Contract news

Four 350 MW boilers for Tilbury power station are being supplied at a cost of over £1 m. by *Lodge Cottrell Ltd* to the Foster Wheeler–John Brown land boiler consortium. The company has also received substantial contracts for the supply of precipitators, one of nearly £1¼ m. from International Combustion Ltd for the new West Burton power station near Nottingham, the other of £440 000 from Dorman Long for a further five precipitators for the new Lackenby works.

*Noyes Bros Ltd*, of Melbourne, Australia, are to supply £1 m. worth of plant and equipment for the basic oxygen steelmaking project of BHP Ltd at Newcastle, New South Wales.

## FORTHCOMING CONFERENCES AND EXHIBITIONS

### Froth flotation remembered

The Minerals Beneficiation Division of the Society of Mining Engineers of the AIME is sponsoring an international meeting in Denver, Colorado, USA on 17–20 September 1961 to commemorate the 50th anniversary of froth flotation in the USA. In addition to papers from US authors there will be contributions from the UK, Canada, Germany, France, and Italy. Preprints will be available at the meeting, and a full report of the proceedings will eventually be issued. Further particulars are available from the Society at 29 West 39 Street, New York 18, NY, USA.

## DIARY

**17–27 Aug.** UNITED NATIONS CONFERENCE ON NEW SOURCES OF ENERGY—Rome.

**20–23 Aug.** 1ST INTERNATIONAL CONFERENCE ON ERGONOMICS—Stockholm.

**30 Aug.–6 Sept.** BRITISH ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE ANNUAL MEETING—Norwich.

**3–12 Sept.** BRUSSELS MACHINE TOOL EXHIBITION—Brussels.

**17–20 Sept.** SOCIETY OF MINING ENGINEERS, AIME—Meeting on froth flotation—Denver, Colorado, USA.

## BRITISH IRON AND STEEL INDUSTRY TRANSLATION SERVICE

The following translations are now available, in addition to those given on page 302 of the July 1961 issue of the *Journal*.

When ordering, please quote the number in bold type.

Electrodes (for arc furnaces). (From French.) PENSA, F. N., *Cahiers du Cessid, l'Acièrie Electrique*, 1957, (1), Pt.3, pp.1–51. (£9) **[943**

Physical properties of coke and their relation to blast-furnace operation. (From German) HIMSEL, W., *Stahl Eisen*, 1958, **78**, Sept. 4, pp.1225–1229. (£3 5*s*. 0*d*.) **[1287**

Comparison of three methods of blowing out blast-furnaces in order to carry out the rapid repairs of the stack. (From German.) ÉTORRE, V., *Centre Doc. Sidér. Circ.*, 1959, **16**, (1), pp.135–155. (£4 5*s*. 0*d*.) **[1288**

The statistical analysis of breakdowns in electrical installations to improve reliability. (With discussion.) (From German.) LOPITZSCH, K.-H., *Stahl Eisen*, 1959, *79*, Sept. 3, pp.1273–1280. (£5) **[1623**

The international development of instruments and controls for the iron and steel industry. (From German.) KRÜGER, H., *Neue Hütte*, 1957, *2*, Feb.–March, pp.103–111. (£5 10*s*. 0*d*.) **[1696**

Resistance to deformation of carbon and nickel steels and alloys. (From Russian.) ZAIKOV, M. A., *Izvest. VUZ Chernaya Met.*, 1958, April, pp.103–116. (£5 15*s*. 0*d*.) **[1845**

Contribution to the study of iron ore from May-sur-Orne (Calvados). (From French.) COURTY, G., *Bull. Soc. Géol. France*, 1959, 7th series, *1*, (5), pp.500–510. (£4 5*s*. 0*d*.) **[1872**

Study of scale formed on strip during hot rolling (From French.) CAGNET, M., and MOREAU, J., *Rev. Mét.*, 1960, *57*, May, pp.437–444. (£3 15*s*. 0*d*.) **[1873**

Towards international standardization of reports on blast-furnace trials. (From French.) THIBAUT, C. G., *Rev. Mét.*, 1960, *57*, May, pp.379–386. (£2 15*s*. 0*d*.) [1895

The applicability of Sim's calculations to hot rolling and the behaviour of the yield stress and deformation resistance in hot rolling. (From German.) WEBER, K. H., *Freiberger Forschungs. Met.*, 1960, B 48, pp.59–88. (£6 5*s*. 0*d*.) [1943

New possibilities in metallurgy made possible by the injection of pulverulent materials into liquid metals. (From French.) ALLARD, M., *Rev. Mét.*, 1960, *57*, Nov., pp.985–989. (£2 15*s*. 0*d*.) [1968

Scientific management staff work in the service of top administration. III. Production planning, order analysis and control with punch cards. (From German.) WEICHSELMANN, F. W., *Stahl Eisen*, 1960, *80*, Nov. 24, pp.1787–1798. (£6 10*s*. 0*d*.) [1974

Production and uses of plastic-coated sheet and strip. (From German.) FRANK, G., *Blech*, 1960, *7*, June, pp.299–309. (£7 15*s*. 0*d*.) [1982

Further development of mechanical weighing equipment for steelworks. (From German.) FRICKE, H., *Stahl Eisen*, 1960, *80*, Oct. 13, pp.1398–1403. (£5) [1997

Some problems of the kinetics and mechanism of the reduction of iron oxide with carbon. (From Russian.) SIMONOV, V. K., and ROSTOVTSEV, S. T., *Izvest. VUZ Chernaya Met.* (Stalinsk), 1960, (4), pp.5–18. (£6 15*s*. 0*d*.) [2003

Chemical-metallurgical studies on welds. (From German.) BORN, K., *Schweissen Schneiden*, 1960, *12*, April, pp.139–146. (£6 5*s*. 0*d*.) [2025

Some problems on testing scale formed in differently fired furnaces. (From Hungarian.) REINHOLD M., *Koh. Lapok*, (Budapest), 1959, *14*, Aug., pp.381–383. (£3 5*s*. 0*d*.) [2041

Preparation technique in electron microscopy. (From German.) MÜHLETHALER, K., *Schweizer Archiv.*, 1960, April, pp.157–162. (£3 5*s*. 0*d*.) [2043

Dependence of specific pressure on rolling speed (with various oscillographic methods). (From Russian.) SEVERDENKO, V. P., Obrabotka metallov davleniem (Sbornik statei) (Mechanical working metals by pressure, coll. of articles), Ed. N. P. Gronov, Moscow, Metallurgizdat, 1952, pp.231–237. (£2 10*s*. 0*d*.) [2047

Determining the coefficient of friction in rolling on a smooth barrel using a radial pressure diagram. (From Russian.) SPIRIDONOV, N. P., *ibid.*, pp.17–41. (£6) [2048

The influence of spectroscopic carbons on problems of spectroscopic analysis. (From French.) RÜSSMANN, H., *Met. Ital.*, 1960, *52*, June, pp.280–288. (£5) [2062

The problem of the quality of large steel forgings. (From French.) BASTIEN, P., *Rev. Mét.*, 1960, *57*, Sept., pp.815–826. (£6 5*s*. 0*d*.) [2067

New possibilities of reducing voltage fluctuation in steelwork grids. (From German.) HAAMANN, K., *Stahl Eisen*, 1960, *80*, Nov. 24, pp.1776–1779. (£3) [2068

The application of digital measuring techniques to metallurgical engineering and research. (From German.) KNÜPPEL, H., and DÖRR, W., *Stahl Eisen*, 1961, *81*, Jan. 19, pp.73–88. (£10) [2082

The production of steel by the LD process. (From French.) WALZEL, R. G., *ATB Métallurgie*, 1960, *2*, (1), pp.13–20. (£8 10*s*. 0*d*.) [2107

The forging of heavy billets between plane tools. (From Russian.) LYU KHAI-KUAN', *et al.*, *Kuznechno-Shtampov.* (Moscow), 1960, *2*, (9), pp.1–5. (£4) [2108

Research on the drawing of small thin-walled tubes of stainless steel. (From Japanese.) OKAMOTO, T., and TAKAHASHI, K., *Tetsu-to-Hagane*, 1960, *46*, (3), pp.311–313. (£4 15*s*.) [2111

Purification of steelworks fumes: basic Bessemer plant and procedures for the refining or pre-refining of pig iron by means of pure oxygen. (From French.) SEPTIER, L., and LEROY, P., *Centre Doc. Sidér.*, (Paris), 1959, *16*, (3), pp.651–678. (£6) This article is a summary of one part of IRSID publication, A.194 (BISI1647). [2118

Testing sinter strength. (From German.) SEND, A., and WEILANDT, B., *Stahl Eisen*, 1961, *81*, March 2, pp.303–311. (£6 15*s*. 0*d*.) [2130

The application of X-ray fluorescent spectro-analysis in the iron and steel industry. (From German.) KOPINECK, H.-J., and SCHMITT, P., *Arch. Eisenhüt.*, 1961, **32**, Jan., pp.19–29. (£7) [2133

Investigation of antique iron components from Cologne cathedral. (From German.) DAEVES, K., *Stahl Eisen*, 1940, *60*, March 21, pp.245–252. (£4 5*s*. 0*d*.) [2134

Studies on mild steel enamelling. I. On the pre-treatment of mild steel plate for one-coat enamelling. (From Japanese). YAMADA, T., *J. Metal Finishing Society of Japan*, 1960, *11*, Feb., pp.10–14. (£6 15*s*. 0*d*.) [2137

S.G. iron for mining machine components. (From Russian.) GORUSHKINA, L. P. *et al.*, *Lit. Proizv.*, 1960, (5), pp.42–43. (£1) [2150

Non-equilibria in adjustment of concentrations of metal and slag in basic converter. (From German.) KOOTZ, T., and UEBERHORST, H. J., *Stahl Eisen*, 1961, *81*, Feb. 16, pp.239–248. (£6 10*s*. 0*d*.) [2151

The new steelworks at Ougrée of the Société Cockeril-Ougrée: Control of the basic Bessemer process. (From French.) FLAMENT, P., *Rev. Univ. Mines*, 1960, (11), pp.463–480. (£8 5*s*. 0*d*.) [2157

A new apparatus for the immediate measurement of the carbon potential of furnace atmospheres. (From German.) SCHMIDT, T., and WÜNNING, J., *Stahl Eisen*, 1960, *80*, Dec. 22, pp.1952–1954. (£2 5*s*. 0*d*.) [2162

The extrapolation of creep-rupture data. (From German.) KRISCH, A., International discussions on long-time behaviour of high temp. steels (Düsseldorf, 1960, June), Paper 9. (£4) [2168

Comparison of various methods of extrapolating rupture data. (From German.) BUNGARDT, K., and SCHMIDT, W., *ibid.*, Paper 10. (£4 5*s*. 0*d*.) [2169

Development of a special ribbed steel for concrete reinforcement (ribbed torsion steel—'Rippen-Torstahl'). (From German.) JANICHE, W., and WASCHEIDT, H., *Beton- u. Stahlbetonbau*, 1961, (1), pp.6–10. (£4) [2170

Developments in the production of blade forgings for steam and gas turbines. (From Russian.) BATAGOV, B. N. *et al.*, *Kuznechno-Shtampov.* (Moscow), 1960, (1), pp.18–20. (£2 5*s*. 0*d*.) [2172

Behaviour of the free gas jet in air. (From German.) MAATSCH, J., *Techn. Mitt. Krupp* (Essen), 1961, March, pp.17–31. (£7 5*s*. 0*d*.) [2179

The electrolytic etching of multiphase iron–chromium–nickel alloys in caustic soda. (From German.) SCHAARWÄCHTER, W. *et al.*, *Arch. Eisenhüt.*, 1960, *31*, June, pp.385–391. (£4 10*s*. 0*d*.) [2181

Hydrogen in steel and its effects. (From French.) BASTIEN, P., *ATB Metallurgie*, 1958, *1*, (5), pp.127–138. (£6 10*s*. 0*d*.) [2186

Development of the processes for the manufacture of broad and parallel flange joists. Actual problems. (From German.) BOLLMANN, K., and KUCHENBUCH, G., *Stahl Eisen*, 1960, *80*, Oct. 27, pp.1501–1507. (£5) [2188

Recent research work on the boron–carbon system. (From Russian.) SAMSONOV, G. V., *Zhur. Fiz. Khim.* (Moscow), 1958, *32*, Oct., pp.2424–2429. (£3) [2191

Exchange between furnace atmosphere and annealed material during works annealing of cold worked strip in a controlled atmosphere. (From German.) SCHMIDT, T., and WÜNNING, J., *Stahl Eisen*, 1961, *81*, March 16, pp.361–366. (£4 10*s*. 0*d*.) [2192

On insuring conditions of high durability of rolls for cold rolling during their manufacture. (From Czech.) KADEBAVEK, Z., *Hutnicke Listy* (Prague), 1960, *15*, (5), pp.355–366. (£10) [2193

Investigation of roll wear with particular consideration of drag rolling in finish rolling hot strip. (From German.) ALTMEYER, H. *et al.*, *Stahl Eisen*, 1961, *81*, Feb. 2, pp.184–194. (£6) [2195

Dilemmas in the present-day development trends of cogging mills and ways of resolving them. (From Russian.) ALEKSANDROV, P. A., Obrabotka metallov davleniem (The working of metals by pressure). Collection of articles No.2, ed. by N. P. Gromov, Moscow, Metallurgizdat, 1953, pp.76–92. (£6 10*s*. 0*d*.) [2196

Recent developments in the field of blast cleaning. (From Dutch.) ZAAT, J. H., *Metalen* (The Hague), 1960, *15*, Aug. 31, pp.277–279. (£2) [2203

The inert gas tungsten arc welding of thin sheet steel for transformers and dynamos. (From German.) RUGE, J., and RAUCHFUSS, W., *Schweissen Schneiden*, 1958, Feb., pp.55–58. (£4) [2213

Increasing the sensitivity of the industrial dilatometer with mechanical recording device. (From Russian.) KISLYAKOVA, E. N., *Zavods. Lab.*, 1955, *21*, (2), pp.240–241. (£1 10*s*. 0*d*.) [2214

Petrographic investigation of converter slags formed during the top-blowing of metal with oxygen. (From Russian.) KARYAKIN, L. I., and IVANOV, E. V., *Ogneupory* (Moscow), 1959, *24*, (10), pp.455–462. (£4) [2216

Wall blocks of electric-arc furnaces from magnesite–chrome brick waste. (From Russian.) KAIBICHEVA, M. N. *et al.*, *Ogneupory* (Moscow), 1960, *25*, (4), pp.186–188. (£1) [2217

Sulphur method of determining oxygen (oxides) in metals. (From Russian.) BABKO, A. K. *et al.*, *Zavods. Lab.*, 1956, *22*, (6), pp.640–645. (£4) [2218

Determination of the rate of hydrogen diffusion in metals. (From Russian.) RYABOV, R. A., and GELD, P. V. *Zavods. Lab.*, 1958, (3), pp.306–308. (£3) [2219

Electrolytic production of coils. (From German.) ECKELMANN, G. Commercial publicity material from G. Eckelmann KG. (£1 15*s*. 0*d*.) [2220

'Skinplate' containers for aggresive contents. (From German.) FRANK, G., unknown. (£2) [2222

Tube welding transformers. (From German.) BOHNEN, J. K., *Blech*, 1960, *7*, Oct., pp.654–657. (£3) [2229

Investigation into the weldability of various grades of plate under the protection of $CO_2$. (With bibliography, 22 refs.) (From German.) GLOCKNER, R., and WIRTZ, H., *Schweissen Schneiden* (Brunswick), 1960, *12*, (11), pp.482–484. (£2) [2241

Looking at tomorrow's methods of steel manufacture. General description of the direct method production of NF type steel. (From Japanese.) NAKASHIMA, S. (NAKAJIMA, T.), *Kinzoku*, 1960, *30*, March 1, pp.28–32. (£15) [2250

The pickling of sheets and the avoidance of pickling defects. (From German.) HOECK, G., *Blech*, 1958, (11),. (£3 5*s*. 0*d*.) [2251

Experiences with direct reading spectrographs in the iron and steelworks laboratory. 10th report. (From German.) HILDEBRAND, H., and DIEHL, W., *Arch. Eisenhüt.*, 1959, *30*, Nov., pp.659–660. (£2) [2254

Comparative examination of iron oxide aerosols and a simple method of producing them. (From German.) SCHÜTZ, A., *Staub*, 1959, Aug. 1, pp.291–296. (£4) [2257

Cast iron containing nodular graphite. Present position of research and developments. (From German.) GROSSMANN, H., *Giessereitechnik* (Berlin), 1960, *6*, Oct., pp.314. (15*s*.) [2262

The casting of half ingot moulds, heavy section plates, flanges, etc., in grey cast iron with an ungated riser. (From German.) SCHOLZ, J., *Giessereitechnik* (Berlin), 1960, *6*, Oct., pp.3–11. (15*s*.) [2263

Quaternary slags $CaO–MgO–Al_2O_3–SiO_2$: initial crystallization temperature and fields of crystallization on constant magnesia planes. (From French.) CAVALIER, G., and SANDREA-DEUDON, M., *Rev. Mét.*, 1960, **57**, Dec., pp.1143–1157. (£6) [2265

Experience in the production and testing in service of graphite-fireclay bricks. [Abridged.] (From Russian.) ZEGZHDA, V. P., *Ogneupory* (Moscow), 1959, (7), (£2 15*s*. 0*d*.) [2278

The service life of graphite-fireclay brick in steel casting ladles and steel furnace launders. (From Russian.) ZEGZHDA, V. P. *et al.*, *Ogneupory* (Moscow), 1959, (9), pp.419–423. (£3) [2279

# ABSTRACTS OF CURRENT LITERATURE AND BOOK NOTICES

*Iron and Steel Manufacture and Related Subjects*

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* Abstracts, the reference to which is marked with an asterisk, are to be made available as translations.

## ABSTRACTS

These abstracts are also available on index cards in advance of publication in the *Journal*, each abstract being classified under the Universal Decimal system (UDC). Details and subscription notes can be obtained from the Secretary, The Iron and Steel Institute.

### MINERAL RESOURCES

**Remarks on the geological situation of the magnesite deposits in the French West Pyrenees** R. Adler and D. Richter (*Z. Erzbergbau, Metallhütt.*, 1961, **14**, 17–23) A detailed geological study of these deposits, with particular reference to their structure (11 refs).

**Iron ore resources of central Sweden** N. H. Magnusson (*Jernkont. Ann.*, 1961, **145**, (1), 1–24) A new estimate of iron ore resources in central Sweden amounting to $650 \times 10^6$ t ores with $255 \times 10^6$ t iron is presented, with a detailed description of the different stages of ore development, and the geological changes in connexion with intrusion of older and younger granites.—S.H.-S.

**Congo holds treasure of iron ore** R. A. Woodtli (*Steel*, 1961, **148**, March 6, 34–35) The author, a Swiss geologist who spent 10 years in the Belgian Congo, and is visiting research associate in geophysics at Pennsylvania State University, reports the existence of two main groups of iron ore bodies in the north-eastern Congo. 200 miles north of the equator, one the Ituri river basin with 45% ore, and the other the Uele river basin with more than 68% ore, with a gross tentative estimate of about $10^9$ t above 45% iron.—S.H.-S.

**Summary of developments in the Canadian mineral industry 1959** B. F. Burke (*Can. Dep. Min. Tech. Survey*, 1959, 1–39) A statistical and analytical review.—S.H.-S.

**Metamorphism of iron formations and its bearing on their beneficiation** G. A. Gross (*Can. Min. Met. Bull.*, 1961, **54**, Jan., 30–36) A brief survey of eastern Canadian iron formations, with data and photomicrographs on ten bodies, one in Labrador, four in Quebec, and five in Ontario, is presented and evaluated as to texture and mineralogy.—S.H.-S.

**Genetic aspects of Michipicoten iron formations** A. M. Goodwin (*Can. Min. Met. Bull.*, **54**, Jan., 38–42) The geological setting of the Michipicoten iron formations is summarized and the genetic aspects of recent work in the area are briefly reviewed and interpreted.

**Origin of the soft iron ores of the Knob Lake iron range** J. B. Stubbins, R. A. Blais, and I. S. Zajac (*Can. Min. Met. Bull.*, 1961, **54**, Jan., 43–58) The deposits, situated approximately two-thirds in Quebec and one-third in Labrador, now being exploited in open-pit mines by the Iron Ore Co. of Canada, are described, with data on general geology and structure, with a regional map, and cross-sections of the Wishart, Gagnon, French, and Redmond mines, with a list of deposits, and tables of physical and chemical properties of the ores, and chemical analyses and photomicrographs. Data on development work are appended.—S.H.-S.

**New rush to the West: Apaches on the ore path** A. H. Fetherolf (*Steelways*, 1961, **17**, Jan., 1–5) Four widely separated centres are discussed: Pea Ridge, Mo., where a huge ore body and beneficiating plant due to produce in 1963 is centred, Silver Bay, Min., where a mine and taconite processing plant is being expanded by 50%, Eagle Mountain, Calif., where beneficiating is being developed to deal with a low-grade iron ore, and Atlantic City, Wyo., which is to become a major steel producer, are reviewed.

**Hisingerite from the Hirako mine in Hiroshima prefecture** K. Takimoto, T. Minato, and S. Hirono (*Suiyokwai-Shi*, 1959, **13**, April, 719–720) Hisingerite, a hydrated ferric silicate occurs rarely in sulphide deposits as gangue minerals associating with calcite and other minerals. In this paper hisingerite from the Hirako mine was mainly studied mineralogically.—R.S.F.C.

### ORES—MINING AND TREATMENT

**The changing world of the extraction metallurgist** F. D. Richardson (*Imperial College of Science and Technology, Inaugural Lecture*, 1958, 103–124) From a ton of ore, the extraction metallurgist may produce 700 lb Fe, 10–100 lb Cu, 2 lb U, or 0·1 oz Au and with the more costly metals a vast shrinkage takes place as the ores are processed. An informative diagram is given showing the shrinkage of an ore containing 5%Cu as it is processed. An operation flow chart for the treatment of the Sudbury sulphide ores is provided and the world production of metals (1867–1957) is discussed. Various aspects of research are reviewed and it is considered that the world of the metallurgist has become so diverse that it is no longer necessary to train men equally in both extractive and physical sides and a degree of specialization must be introduced in the final undergraduate year; also, knowledge has expanded so greatly that a three-year course is insufficient for such a subject.—C.V.

**Iron** H. T. Reno (*US Bur. Mines Bull.*, 1960, (585), 403–421) A general review. Mining, resources, beneficiation, and such topics are mainly dealt with.—C.V.

**Progress in walking draglines** C. McL. Cameron (*Edgar Allen News*, 1961, **40**, Feb., 25–30) The development of walking draglines is outlined, and the working conditions, and material used to satisfy these conditions, are described.

**Iron ore mining in Goa** N. Dekowski (*Z. Erz. Met.*, 1960, **13**, Aug., 373–381) An account of the deposits in Goa, their mining, and transport to the coast. Some production data and costs are given.

**Iron ore work booms in Canada** T. Campbell (*Iron Age*, 1961, **187**, March 9, 62–63) The developments of Quebec Cartier Mining Co. and of Iron Ore Co. of Canada now nearing production in Quebec and Labrador are briefly described.—S.H.-S.

**Methods and costs of producing brown iron ore at two small southern Missouri mines** H. D. Kline (*US Bur. Mines, Inf. Circ.*, 7983, 1960, pp.18) The history, location, physical features, and geology of the ore deposits are summarized. The Sawyer and Fore mines showed a recovery of 66 and 47·58%Fe in the crude ores with a P-content in both cases of ~0·045%. The operational costs are discussed.

**Marcona of Peru** (*Met. Bull.*, 1961, Jan. 31, i–iv) The deposits, plant, equipment, and operations of the Marcona Mining Company, the leading Peruvian iron ore enterprise, are described, with data on ore-beds, and analyses of lumpy ore, sinter feed, and pellets.—S.H.-S.

**Blending iron ore at Stanton** (*Min. J.*, 1961, **256**, Feb. 10, 152–153) Initially furnaces were charged with run-of-mine ore delivered direct to furnace bunkers. Now all incoming ores are blended and fines are sintered. Ores come from many sources and some 35 000 t/week can now be handled by this new plant. Details of the plant and the layout are provided.—C.V.

**Swedish ore in transit** P. Hewitt (*Ingot*, 1960, Oct., 1–12) Luossavaara and Kiirunavaara

with Malmberget produce some $13 \times 10^6$ t of ore each year; some $1\frac{1}{2} \times 10^6$ t are exported to this country through the ports of Narvik and Lulea. The P-content of some of the ore is noted and before being sent to the ports it is crushed, sorted, concentrated, and pelletized.

**Steel port and harbour improvement work** (*Far East Iron Steel Rep.*, 1960, **69**, Oct., 9–10) [In English] Details are given of harbour improvements at 14 Japanese ports serving the steel industry to allow importation of increased quantities of iron ore. Carriers in the 40 000-ton class are to be accommodated.—K.E.J.

**Marginal ores upgraded by magnetizing roasting** D. J. Hains (*Steel*, 1960, **147**, 72, 74) Beneficiation processes to make marginal iron ores from the Minnesota fields marketable at reasonable cost, embodying kilns, travelling grate machines, shaft furnaces, and fixed bed reduction, with their operation, are briefly described, and test equipment presented.

**Semi-taconite yields iron** M. A. Hanna Co. (*Steel*, 1961, **149**, March 13, 107) An iron concentrate, produced by kiln roasting semi-taconite (a combination of hard rock and small amounts of iron from the Werlen and of the Mesabi range), is presented as a supplement to US iron ore supply.—S.H.-S.

**Application of probability in the assessment of flotation systems** D. F. Kelsall (*Bull. Inst. Min. Met.*, 1961, Jan., 191–204) Probability and separation factor methods of assessment of flotation results are compared, and an example is given of the application of probability to the correlation of pilot-plant flotation with full-scale flotation. The paper concludes with practical illustrations of the use of the method at Nchanga Consolidated Mines, Ltd.

**Recovery of nickel and cobalt from lateritic iron ores** P. M. Heertjes and C. L. Van Nes (*Rec. Trav. Chim. Pays Bas*, 1960, **79**, 595–664, June) [In French] Recovery of Ni and Co from lateritic iron ores was achieved by converting their oxides almost selectively and completely into the corresponding chlorides. A step-wise process was used in which a gaseous mixture of steam and HCl was passed through a fluidized bed of the granulated ore under suitable temp. and concentration conditions. The chlorides were recovered by extracting the product with hot water.

**Recovering cobalt and nickel from complex ores of south-eastern Missouri** K. K. Kershner and F. W. Hoertel (*US Bur. Mines, Rep. Invest. No.* 5740, 1961, pp.16) Sulphide ore concentrates containing Co, Ni, Cu, Pb, and Fe were salt roasted and leached on a laboratory scale and >95% of Co, Ni, and Cu was recovered. The conditions were established, 375–400° being the optimum for salt roasting. Metal chlorides were leached at pH=1 from chloridized charges of these concentrates and although the amount of Co, Ni, and Cu extracted was high, the dissolved Fe interfered with subsequent separation. Preliminary steam treatment at 300° considerably reduced the amount of dissolved Fe (35 refs).—C.V.

**Opening of the columbite concentrate with hydrofluoric acid** I. Kushima, J. Moriyama, and S. Nishimura (*Suiyokwai-Shi*, 1959, **13**, April, 735–739) The authors studied an effective procedure for opening the Nigerian columbite concentrate with HF. The following items were selected as the factors influencing the opening of the ore: (1) opening time, (2) opening temp., (3) HF-to-concentrate ratio, (4) time of stirring, (5) grain size of the ore, (6) addition of $HNO_3$ or $H_2SO_4$. From the experimental results it was found that a nearly complete opening of the concentrate could be obtained by leaching with 55%HF, when it was ground to pass through 200 mesh sieve and thoroughly stirred in a polyethylene refluxing apparatus maintained at 80°.—R.S.F.C.

**On the behaviour of pyrites in the roaster** K. Nishihara, Y. Kondo, and K. Hori (*Suiyokwai-Shi*, 1959, **13**, April, 721–724) The intensity of magnetization was measured and the thermomagnetic analysis was performed with the following samples: (a) fine ore taken from the roasting hearths of the Herreshoff furnace, and (b) lump ore taken from the interior of the lump pyrites kiln. From the results of the measurements the behaviour of pyrites in the roaster was summarized.—R.S.F.C.

**Tests of the reducibility of pyritic ash sinters made separately or from mixtures with other ores** J. A. Boned Sopena, J. Asensio Gonzalo, and A. Fillol Ciorraga (*Inst. Hierro Acerro*, 1960, **8**, Oct.–Dec., 882–904) The reducibility of the sinters has been studied as a function of the charge, the heat level of sintering, which was varied by varying the calorific intensity of the firing, and the proportion of returned fines in the charge. The reducibility was evaluated by means of measuring the reduction velocity constant. Full experimental data and a statistical analysis of them are provided to show the relationship between the reducibility and the properties of the sinters (12 refs).—P.S.

**Sinter plant data logger aids analysis control** Youngstown Sheet and Tube Co. (*Steel*, 1961, **148**, March 20, 104–107) A digital computer to control process data, including instantaneous X-ray analysis of raw materials and final product in sinter production, is described.

**On sintering tests of hematite ore fines in self-fluxing sinter** T. Sanematsu, S. Kiriyama, and H. Toyozawa (*Sumi Met.*., 1960, **12**, April, 380–386) [In Japanese] Effects on the productivity and the sintering operation of added hematite fines were examined in the test sintering pan and on the plant. With 20% fines, 4% coke should be added; productivity varies with the source of the ores; and coarse additives should be avoided.

**Some aspects of airflow through sinter beds** D. W. Mitchell (*JISI*, 1961, **198**, Aug., 358–363) [This issue].

**From the history of the blowing process for the sintering (agglomeration) of iron ores** W. Troeller (*Rev. Techn. Luxembourg*, 1960, **52**, Oct.–Dec., 227–229) An account of the early development of 'converter sintering' is followed by an outline of the Dwight-Lloyd patents, and of the use of the Dwight-Lloyd equipment for the sintering of iron ores.

**Control of some variables of the sintering process and sintering characteristics** G. Sironi (*Met. Ital.*, 1960, **52**, Dec., 828–834) [In Italian] Careful control is necessary of factors influencing the production of sintered material such as charge composition, water content, permeability, and fuel contents. These problems and those concerned with the technological characteristics of mixed changes are discussed with regard to both Italian and foreign tests.

**Factors affecting the strength of self-fluxing sinter** S. Temesi (*Koh. Lapok*, 1960, **93**, Dec., 553–558) According to recent Hungarian experiments, the main factors affecting the strength of self-fluxing sinter are the carbon content and the basicity of the mixture. A basicity higher than 1 is detrimental. Replacement of limestone with dolomite seems to be advantageous up to 4%MgO content in the mixture.—P.K.

**Conditions for desulphurization during sintering** D. T. Khokhlov (*Stal'*, 1961, (3), 193–197) The removal of sulphide sulphur is discussed and numerous trials are described. Sulphur can be removed to the extent of 96–98% oven with as much as 3% present initially. Improved mining and concentration and millscale addition, efficient mixing, and crushing before sintering are important. In the sinter process, higher temperatures, replacement of limestone by dolomite, and minimizing slag-forming constituents with exclusion of lean ores bring about great reductions in S.

**The metallurgy of reduction processes in rotary tubular kilns. 2. Investigations of the reducibility of ore pellets** M. Wahlster (*Techn. Mitt. Krupp.*, 1961, **19**, March, 1–16) Hematite pellets of different origins were reduced in rotary kilns by means of solid reducing materials with determination of the conditions of the process. The test procedure, reactions, influence of different reducing agents, the increase in C and S content, and the tests on the finished pellets are described.—M.L.

**Magnetic balance for determining the degree of reduction of iron ores** A. Winkelmann (*Techn. Mitt. Krupp.*, 1961, **19**, March, 32–36) A magnetic balance is described which is used to determine the degree of reduction of Fe ores, the principle being the measurement of the saturation magnetization. The advantages are operability by unskilled operators, low analysis cost, accuracy equal to chemical analysis, and reproducibility of the results. P, S, C and other impurities may interfere and require calibration curves with known amounts of impurities.

## FUEL—PREPARATION, PROPERTIES AND USES

**Reducing the specific furnace coke consumption** C. Marcu (*Met. Constr. Masini*, 1960, **12**, (11), 1009–1013) Reduction of the specific furnace coke consumption reduces production costs in the iron and steel industry and can be brought about by reduction of the slag (which can be obtained by enrichment in Fe and homogenization of the ores) and by reduction of heat losses, as well as by improvement of the granulation of ore, lime, and coke. Special procedures, like operation with higher pressures at the furnace neck, addition of methane, or humidified air also improve the coke economy.—M.L.

**Energy economies in ironworks** K. Godyn and J. Kawa (*Hutnik*, 1960, **27**, (11), 424–440) The article gives statistical information on production and energy consumption in the period 1946–53 for one particular ironworks in Upper Silesia. A complete heat balance is drawn up for the following plants: coke ovens, blast-furnaces, and electric furnaces, sinter plant, and rolling mills. The article is illustrated with diagrams and graphs.

**Field description and sampling of coal beds** J. M. Schopf (*Amer. Geol. Survey Bull.*, **1111–B**, 1960, pp.70) Information required in describing coal beds, with a discussion of sampling methods and applications for coal geology, is presented as a contribution to general geology.

**Relationship between the coal classification parameters on the basis of studies of the South-Mecsek bituminous coal seams** P. Takacs and L. Jako (*Bergakademie*, 1961, **13**, (1), 1–8) The data obtained on South-Mecsek bituminous coal was analysed by determining the relations between the five classification parameters, when arranged in pairs of mutually deviating (volatiles/Roga index) or complementary (Roga index/expansion) character. It was determined that both the EWK and Sapoznikov classification systems are suitable for the characterization of fundamental coking properties, but the latter comprises more explicit characteristics which are obtained by one determination only (12 refs).—M.L.

**An improved method for float-and-sink analysis with coals of under 3 mm particle size** G. G. Sarkar and S. J. Manchanda (*Glückauf*, 1961, **97**, Feb. 15, 204–206) The apparatus described is designed to give accurate and reproducible results and to fulfil safety requirements. Standard deviations of $\pm 0{\cdot}11$ for 3–0·5 mm and $\pm 0{\cdot}25$ for >0·5 mm are reported.

**Coal and coal seam composition as related to preparation and carbonization** W. Spackman, W. F. Berry, R. R. Dutcher, and A. H. Brisse (*AISI*, 1960, reprint, 403–450) For certain high volatile A coals the, vitrinite content and vitrinite:micrinite ratio gives a means of predicting coke strength. The attainment of max. coke strength requires an optimum plastic:non-plastic ratio. Ash+fusinoid +micrinoid (AFM) gives a gross index of the final expansion or contraction properties exhibited by some medium-volatile coals. Three major types of heterogeneity are important, (a) the particular macerals and minerals present, (b) that induced by the particular lithobodies being processed, and (c) that resulting from the mining and preparation procedures. The necessity for pulverizing and thorough mixing will be appreciated where heterogeneity is concerned. Thirteen strata of the 'Mary Lee' seam, (Birmingham, Ala.) have been examined.—C.V.

**Carbonizing properties of Wyoming coals** W. S. Landers, V. F. Parry, M. Gomez, E. O. Wagner, J. B. Goodman, and C. R. Nelson (*US Bur. Mines, RI* 5731, 1961, pp.74).

**Coking characteristics of selected Australian and Japanese coals** C. E. Marshall and D. K. Tompkins (*J. Proc. Roy. Soc. NSW*, 1961, **94**, Jan. 26, 121–172) A laboratory-scale investigation of the coking characteristics of Australian and Japanese coals, both individually and in blends is described. The value of small-scale tests is discussed and the importance of seam

characteristics, methods of charge preparation, controlling size and maceral distribution, and conditions of carbonization are emphasized. Adoption of a uniform 'standard' charging temp. suitable for most of the coals studied is suggested.—S.H.-S.

**The Grange coking plant of the Steel Company of Wales** (*Coke Gas*, 1961, **23**, Feb., 55–62) A detailed description of the new Simon-Carves coke and by-products plant near the Abbey steelworks is given, together with an account of the planning and site preparation.

**News of the operation of Soviet coking plants** B. Šplíchal (*Hutn. Listy*, 1961, **16**, Feb., 77–78) [In Czech] Knowledge obtained during the visit of Czech specialists to the USSR is summarized. The author deals with the organization of the Soviet coking industry, coke chemical research, planning of coke chemical works, and with the modernization of Soviet coking plants.—R.S.F.C.

**X-Ray investigation of cokes and coals: The structure of blast furnace cokes** A. M. Zubko ('*Problems of Metallography and the Physics of Metals*', 1959, 32–38; translated from Russian) The earlier views concerning the formation and growth of graphite crystals is briefly reviewed and it is shown that the present experimentation leads to different conclusions; diffraction pictures showing that after firing at very high temp. only asymmetric maxima (hkO) and graphite lines (001) appeared, it being found that in the curves of radial distribution of the atoms (C-blacks and cokes) the maxima, corresponding to the interatomic distances of the various lattices, were absent. It is concluded that in amorphous carbons, the C atoms are grouped in two-dimensional lattices similar to the basic lattice in the graphite crystal and that the lattices are disposed parallel to one another without any correlation. Coke from different plants and from different locations in the furnace are compared and similar studies are carried out in the laboratory under vacuum.—C.V.

**State gas** (*IV Argentine Eng. Congress*, Sept., 1959: Buenos Aires, 1960, March, 7–101) A review, in five sections, describing: (1) the situation in the national gas complex; (2) formulae for the transport of natural gas by pipe lines; (3) the Campo Dursa gas system; (4) the production of natural gas in the Argentine petroliferous fields; (5) the conversion of 420 000 manufactured gas-users in the city of Buenos Aires to the use of natural gas.

**Some methods of producing gas for heating furnaces** E. J. Lawton (*Glass Techn.*, 1961, **2**, Feb., 11–22) Single- and two-stage producers, oil gas, partial combustion, OCCR, Koppers-Hasche, Catalytic, Distrigaz, Otto, and MS processes and the Urquhart high-duty gasifier are briefly described. The MS plant has many advantages over any other type of gas-making plant since gas is the only product, the fuel is essentially S-free, the combustion characteristics are constant, little supervision is required and capital cost is low and there is no tar, carbon, or effluent to be dealt with (21 refs).

**A two-stage gas producer and its application** A. H. O. Johnson (*Glass Techn.*, 1960, **1**, Dec., 260–267) The practical development of commercial plants for the production of three types of producer gas (hot raw gas, hot detarred gas, and cold clean gas) is described and operating data are provided for the operation and utilization of these gases. Methods of cleaning and treatment of by-products are described, together with the disposal of effluents. The economic advantages are indicated.—C.V.

**Preheating of producer gas in regenerative furnaces** G. A. Sparham and D. W. Gill (*Glass Techn.*, 1961, **2**, Feb., 23–24) In industrial generators there is no critical temp. for the decomposition of tar and that which takes place depends on the gas flow pattern and the final preheat temp. There is no serious loss of potential heat as the result of soot deposition and the total heat content of the gas (including sensible heat) increases with increasing preheat temp. As most of the soot produced is carried into the furnace and since soot may be expected to be as good a luminant as tar, there is no appreciable change in luminosity resulting from tar decomposition. Only at preheat temp. $>1100°$ when soot is transformed into CO is the luminosity affected, but such temp. are not likely in a conventional regenerative furnace except in special conditions.—C.V.

## AIR POLLUTION, DUST AND SMOKE

**Instrument for recording the dust nuisance emitted by chimneys** P. A. E. Crosse, D. H. Lucas, and W. L. Snowsill (*J. Sci. Instr.*, 1961, **38**, Jan., 12–17) A new type of instrument and its method of operation are described, which measures the difference between optical obscuration produced by a clean glass surface and when dust collected by a flue dust has settled on it. It is claimed to operate over a large range of signal levels, and to facilitate control of dust emission from industrial chimneys.—S.H.-S.

**Laws of turbulent gas diffusion as a basis for the determination of minimum chimney heights** J. Drimmel, H. Fortak, E. Geisler, G. Hollmann, W. Klug, H. Reuter, H. Stümke, and F. Wippermann (*VDI Forsch.*, 1961, **37B**, (483), pp.52) In order to determine the factors governing the laws of turbulent gas diffusion, which may serve as basis for the determination of minimum stack heights, a series of independent studies were carried out, attempting to refine and improve the existing method based on O. G. Sutton's theory. The refinements take into account the vertical elevation of the flue gases over the stack mouth, the effects of measuring time and time of emission, the variability of the atmospheric stability with height, improved determination of the exponent in the Lagrange correlation function, the extension of the method to low wind velocities, and the possibilities of evaluating the relevant meteorological parameters (58 refs).—M.L.

**Electro precipitators: Practical design aspects** J. E. Sayers (*Howden Quart.*, 1960–61, (45), Winter, 21–30) The various problems are discussed in some detail. A brief description of some typical installations in power stations and steelworks is also given.—C.V.

**Electro-precipitator for South Durham Steel & Iron Co. Ltd, Cargo Fleet Works, Middlesbrough** (*Howden Quart.*, 1960–61, (45), Winter, 16–17, 20) This is of horizontal design and treats the dust-laden gases from the steel-making process of a 300-t OH furnace equipped with oxygen blowing. The gas temp. leaving the waste heat boiler is $\sim 300°$ but if the boiler is by-passed 600° is possible. Cooling to 150° is required and the gas must be conditioned by the addition of moisture; 90% of the dust particles are $<1\ \mu$ and precipitation is necessary. The Howden Lurgi Electro Precipitator is of parallel plate design with interposed wire or other suitable discharge electrodes arranged for horizontal gas flow. A high uni-directional voltage is applied to the discharge electrodes which sets up a corona discharge causing a stream of electrons and negative gas ions to travel continuously across the gas stream of the collecting plate electrodes. When the electrodes are tapped the dust falls into a zone shielded from the gas flow, The details as to voltage, transformers, rectifiers, etc., are indicated.—C.V.

**Blast-furnace gas cleaning plant** (*Gas Coke*, 1961, **23**, Feb., 80) The Appleby-Frodingham Steel Company has constructed a gas cleaning plant to handle 8 100 000 ft³/h to a final standard of 0·005 grains/ft³. The main items of equipment are two 18 ft dia. Head Wrightson McKee gas washers and four 23½ ft dia. Head Wrightson Research precipitators. The limited ground area available, 120 ft square, divided by a railway line, was one of the numerous difficulties to be overcome.—C.V.

**Cleaning of gases from converters top-blown with oxygen** L. V. Sudoplatov and A. M. Saksaganskii (*Stal'*, 1961, (3), 286–288) An inclined water-cooled tube with a hood as near as possible to the converter mouth was put in. This greatly improves the collection and trapping of fume but is not itself sufficient, and projected additions to reduce the concentration further in the waste gas are indicated.

**Hot gases from electrics cleaned with glass bags** Joy Manfg. Co. (*Steel*, 1960, **147**, Oct. 31, 74) Control of steel plant dust and fumes from electric furnaces, by a system of collector hoods and high temp. filter bags of silicone treated Fibreglass, handling gases at temp. up to 600°F is described.—S.H.-S.

**Process development in removing sulphur dioxide from hot flue gases. 1. Bench-scale experimentation** D. Bienstock, J. H. Field, and J. G. Myers (*US Bur. Mines, Rep. Invest.* 5735, 1961, pp.29).

## REFRACTORY MATERIALS

**Refractories industry in India** N. R. Srinivasan (*Central Glass Res. Inst. Bull.*, 1960, **7**, (2), 87–89) The consumption and demand are tabulated.—C.V.

**Researches on the constitution of steelworks refractories** K. W. Andrews (*Refract. J.*, 1961, **37**, March, 66–77) A paper, reviewing the value of various techniques, especially methods of X-ray diffraction and microradiography, with examples of research in silica refractories, fireclay bricks, and basic refractories. Problems in connexion with the crystal chemistry of these materials, leading to the elucidation of some new principles affecting the pressure of chromium in refractories and slags, are investigated and discussed.—S.H.-S.

**The selection of refractories in common use** E. Masters (*J. Jun. Inst. Eng.*, 1961, **71**, Jan., 88–95) A succinct review. The reactions between the various refractories (9) at four temp. (1500–1 700°) are tabulated and the behaviour of the three main forms of silica and their conversions are reviewed.—C.V.

**Basic refractories in the iron and steel industry** M. Macola (*Met. Ital.*, 1960, **52**, Dec., 895–902) [In Italian] After a general review of the raw materials used for basic refractories, the various types of basic bricks and particularly recently developed chromite, unburnt magnesite, and boxed bricks are described, also in relation to their behaviour in furnaces.

**Recent developments in silica, silico-alumina, alumina and special bricks for the iron and steel industry** F. Savioli (*Met. Ital.*, 1960, **52**, Dec., 903–910) [In Italian] It is shown that the consumption of refractories by the iron and steel industry is tending to decline and this is coincident with an increase in demand for special high quality products which will increase turnover, but to achieve this the refractory industry must install the plant necessary to satisfy the new demands. To this end there must be increased co-operation between technicians on both sides.

**Quality and applications of Belgian blast-furnace cements. I.** L. Blondiau (*Silicates Indust.*, 1961, **26**, 32–39) [In French] Properties and uses are surveyed. In most respects the cements are virtually equivalent to Portland cement.—F.P.

**Science in the ceramic industry** N. F. Astbury (*Trans. Brit. Ceram. Soc.*, 1961, **60**, Jan., 1–32) A general survey is given of the problems posed by the definition given of the art of ceramics as 'a system in which minerals of inconstant composition and doubtful purity are exposed to immeasurable heat long enough to carry unknown reactions partly to completion, forming heterogeneous, non-stoichiometric materials'. Specially dealt with is the structure of clay slips, the effect of contamination on the heating of a kaolinite clay and of heterogeneity on a fired clay with special reference to its mechanical properties, the durability of pottery decoration, and finally on special refractory materials used for the development of chrome-magnesite bricks and the question of non-metallic inclusions in steel. A note is included on special ceramics such as $Si_3N_4$, BN, and BP.—C.V.

**The dilatometric behaviour of quartzites and sandstones under the effect of heat** K. Kohler (*Radex Rundsch.*, 1961, April, 536–542) The factors influencing increased dilation and contraction of single crystals and polycrystalline aggregates under the effect of heat were discussed. The effects of the bonding medium and the grain size on the dilatometric behaviour of not regulated quartzites and sandstones was investigated, determining a low coefficient of dilation in the case of fine-grained quartzites and sandstones with not-quartzified bondings. An approximate equation was derived, connecting the dilation coefficient with the grain size (24 refs).—M.L.

**The drying of magnesite from sea water and sintering of the oxide formed** A. Branicki, S. Fruchter, and A. Kathrein (*Acad. Romine Studii Cerc. Met.*, 1960, **5**, (4), 547–568) The processes of dehydrating $Mg(OH)_2$ prepared by precipitation from sea water with lime, and sintering the resulting MgO were studied, determining that most of the water of constitution is lost at up to 700°C and that sintering with the various customary additives gives a satisfactory sintered magnesia after 12 h at 1700°C. X-ray diffraction studies indicated structural identity between $Mg(OH)_2$ and MgO from sea water and those obtained from giobertite.—M.I.

**The new Ougrée steelworks of the Société Cockerill-Ougrée. The dolomite shop** R. Dodet (*Rev. Univ. Mines*, 1960, **103**, Nov., 459–463) The plant and its equipment are described, and its applications outlined.

**Advances in dolomite technology** D. F. McVittie (*Refract. J.*, 1961, **37**, Jan., 2–6) A survey of the existing uses and comparison analyses of different types of dolomite with methods of application, and a reference to the sea water magnesite process.—S.H.-S.

**Anchoring arrangement improves monolithic lining performance** (*Industr. Heat.*, 1961 **28**, Jan., 155–156) The system finally adopted by Harbison-Walker Refractories Co. embodies a slotted super-duty fireclay anchor, of height equal to the lining thickness, and metal hangers (heat-resistant cast alloy for roofs, Cr-Ni for walls.—K.E.J.

**Practical trials with high alumina refractories in a Cowper stove at Workington** J. Y. Lancaster (*Iron Coal Trades Rev.*, 1961, **182**, Feb. 10, 291–294) The first trials show that this refractory is superior to that of the ordinary quality; the best performance was given with materials naturally high in alumina and among the synthetic clay/bauxite group, that with the lowest porosity gave the best results. The assessment of test performance (comparison of laboratory with plant) is discussed and a close correlation was obtained. The benefits that may arise in coke and production rates resulting from the higher blast temp. are indicated.—C.V.

**Treatment of thermal equilibria for stabilized dolomites** S. Solacolu (*Refract. J.*, 1961, **37**, Feb., 34–42) The phasic thermal equilibria of the five-component sub-system MgO–$C_2S$–$C_2S$–$C_3A$–$C_4AF$ are determined (C=CaO, A=$Al_2O_3$, F=$Fe_2O_3$, and S=$SiO_2$). The five-component bounding surface on which the thermal equilibrium process takes place was investigated and this led to the elaboration of formulae which show the amounts of solid and liquid phases in equilibrium at high temp. A five-component bounding surface conic projection diagram was prepared. A correlation was found between the quantity of liquid phase (deduced from the relations of thermal equilibrium) and the properties of the refractories and it was found that these properties are not only a function of the liquid phase content but also of the solid phases in equilibrium with it, and, in the first instance, the mineralization of the periclase.—C.V.

**Mechanism of solid-state reaction between magnesium oxide and aluminium oxide and between magnesium oxide and ferric oxide** R. E. Carter (*J. Am. Ceram. Soc.*, 1961, **44**, March, 116–120) Inert marker experiments show that the solid-state reactions forming $MgAl_2O_4$ and $MgFe_2O_4$ occur by the counter-diffusion of $Mg^{2}$, $Fe^{3}$, and $Al^{3}$ ions through the relatively rigid O-lattice of the spinel or ferrite. The formation of $ZnAl_2O_4$ is considered; earlier it was thought that the diffusion of $Zn^{2}$ and $O^{2}$ ions was responsible leaving some marker on the surface specimen but pores in one component of a reacting couple are shown to serve as inert markers. This work now enables the ferrites and stannates, which dissolve marker materials, to be studied.—C.V.

**The free energy of formation of mullite** A. C. Cooper, D. A. R. Kay, and J. Taylor (*Trans. Brit. Ceram. Soc.*, 1961, **60**, Feb., 124–134) The free energy of formation of mullite from its constituent oxides has been determined from the equilibrium in the reaction $Al_2S_3+6C=3Al_2O_3+2SiC+4CO$. The free energies of formation of andalusite, kyanite, and sillimanite are discussed in the light of these data. It is shown that these values agree with the results of Aramaki and Roy regarding the mullite/$Al_2O_3$ boundary in the C.A.S. system.

**Properties of complex silicon nitride-bonded silicon carbide refractories related to industrial applications** R. W. Love (*Indust. Heat.*, 1961, **28**, Jan., 140–150) Crystolon '63' has applications in Al reduction cells, reverberatory furnaces, transfer systems for non-ferrous metals, structural parts of boilers and incinerators, heat-treatment furnaces, plant needing wear resistance, and the missiles and chemical industries.—K.E.J.

**Titanium diboride high-temperature refractory—produced by improved process** National Carbon Co. (*Indust. Heat.*, 1961, **28**, Jan., 137–138) This material maintains a flexural strength of 35000 lb/in² over the range 25–2000°C. Hardness, oxidation resistance, electrical, and other properties are given. A very fine, high-purity powder is made by National Carbon Co., and made into shapes of size up to a cylinder of dia. 14in and length 10in.—K.E.J.

**Tensile strength of Spanish refractory materials. Comparative statistical study of tensile, compression and bend tests** V. Gomez Garcia (*Inst. Hierro Acero*, 1961, **14**, Jan., 88–91, *Special Number*) [In Spanish] The results of a series of tensile tests on refractory bricks of high silica, alumina–silica, and magnesite types of Spanish origin are reported and included with the previously reported results of compression and bend tests. The combined results are examined statistically.—P.S.

**Perfecting the refractoriness test with spherical test pieces** R. Zoja (*Met. Ital.*, 1960, **52**, Dec., 911–912) [In Italian] In order to improve testing conditions and increase the spread of the values of the refractoriness index the dia. of spherical test-pieces has been increased from 20 to 25 mm. By using a Tamman furnace with an internal dia. of 165 mm a dimension of 40 mm for test piece dia. has been obtained. The preliminary results of tests carried out with the new methods on high-magnesia blast furnace slags are illustrated.

**The use and significance of tests on refractories** J. Jamais (*Silicates Indust.*, 1961, **26**, 25–31) [In French] Methods of testing refractories, and the practical significance of the tests are discussed.—P.F.

## IRON AND STEEL—GENERAL

**Recent data on the development of the Chinese metallurgical industry** P. Arnold (*Mét. Constr. Mécan.*, 1961, **93**, March, 171–172, 175) Chinese metallurgy has made substantial progress in recent years. Items of information which may be considered reliable are analysed and substantial known reserves of essential ores are tabulated.—S.H.-S.

**China's iron and steel works** X. Wuhan (*Met. Bull.*, 1961, Feb. 21, i, iv) A general report; the first phase of construction is said to be about completed, the present capacity being $1{\cdot}5\times10^6$ metric t pig iron and the same tonnage of steel while the output for 1963–1968 aims at double this figure. The ore is mined locally.

## BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

**Up-to-date blast furnace operation** P. Pilter (*Koh. Lapok*, 1960, **93**, Nov., 512–517) The author deals with the composition and preparation of blast-furnace burden, the effect of increasing blast temp., and the removal of S and Si from molten pig iron (hot metal).

**Fast preparation for blast furnace relining** (*Engineer*, 1961, **211**, March 3, 340–342) The various steps are outlined. Grant, Lyon and Company of Scunthorpe has developed a special technique for blast-furnace lining removal. After the 'salamander' has been tapped, the remainder is left to solidify and about 750000 gal or more of water is pumped in to complete the cooling. The point of, and method of, break through is described, together with the removal of the burden by power shovel. The time taken may vary between 2½ h and 3–4 days depending on conditions. A breach is also formed in the hearth jacket as low as possible and of sufficient size to allow a forward-loading shovel to enter. Once the wrecking commences, it continues for 24 h a day until the furnace is completely clear to hand over to the bricklayers for relining. The time for completion depends on many factors, but work on a 25–27 ft dia. hearth has been completed in 2–3 weeks.

**A correct interpretation of blast-furnace processes** W. Kuczewski (*Hutnik*, 1961, **28**, (1), 17–21) The author disagrees with E. Bonnaure's view (*Stahl Eisen*, 1959, (16) ) that the production rate depends solely on elimination of the inactive zone and increase in the volume of blast. In the author's view, the elimination from the burden of anything that is not perfectly reducible is far more important, perfect reducibility meaning that the heat and the chemical energy of the reducer and the ore reduced should be fully utilized. In using sinter its quality should be such as to make possible the diffusion of C and metallic Fe particles from the surface of a lump into its inside. E. Bonnaure's research however has confirmed the author's previous theoretical considerations which indicated that both direct and indirect reduction as well as Bell's reaction do take place simultaneously in the same part of the ore.

**The use of fuel-air in the blast-furnace** Z. Punčochář (*Hutník*, 1961, **11**, (1), 3–11) [In Czech] The technological and economic aspects of the use of fuel- and oxygen-enriched blast are surveyed, mainly on the basis of recent Soviet publications. It is urged that the rapid introduction of the method be considered with a view of increasing blast-furnace productivity in Czechoslovakia.—P.F.

**Distribution of the internal pressure of charge in blast-furnaces** F. Gémes (*Koh. Lapok*, 1960, **93**, Sept., 408–414) The factors affecting the distribution of the internal pressure of charge in blast-furnaces are experimentally determined on models, and their effect is expressed graphically, as well as mathematically.—P.E.

**Analysis of heat-exchange processes in the blast-furnace** B. L. Lazarev, B. I. Kitaev, and Yu. G. Yaroshenko (*Stal'*, 1961, (3), 200–206) An exhaustive thermodynamic study with tracing and discussion of the temp. gradients in the furnace is presented. The results are largely given in terms of the water equivalents of the charge and the gases in contact and the relations between these for optimum operating conditions are indicated.

**Thermochemical calculations of the blast furnace process** R. Linder (*Jernkont. Ann.*, 1960, **144**, (12), 859–967) In the method described, the influence of different variables on coke consumption determined by dividing the burden column into five heat-consuming zones and one combustion zone. The reactions and heat requirements are examined, and their effects on coke rate considered in the light of typical Swedish practice (34 refs).

**Regulation of blast furnace work with the charging installation** M. Kowalski (*Hutnik*, 1960, **27**, (11), 413–416) The author deals with the uneven distribution of the charge in the throat which is caused by uneven distribution in the rotating parts, affected in turn by the physical properties of the material and its size and speed of rotation. In the case of blast-furnace the uneven distribution in the horizontal plane has to be considered as distinct from that in a vertical plane. In the horizontal plane correction can be carried out by controlling the charging programme and in the vertical plane by the charging method, size of charge, etc. For optimum result the correct size of coke must be used.

**Smelting special ores** (*Min. J.*, 1961, **256**, Jan. 27, 97) The use of the Krupp-Renn process for low-grade siliceous ores (30–35%Fe; up to 40%Si) is discussed; the high S content in the resulting metal makes it unsuitable for steelmaking and it is usually charged to the blast-furnace; this process therefore is more beneficiation than smelting. The RN for low grade ores has several advantages; these are considered. Ti-ores are considered unsuitable for the blast-furnace but use of the Tysland-Hole electric furnace enables smelting to take place without a high Ti-content metal resulting; the Strategic-Udy process has been used on a pilot scale with a $TiO_2$ content up to 25%.

High and low Mn–Fe ratios are discussed using the RN and SU processes. In the Sturzelberg process the ore after calcining to remove S is fed into a short reverberatory furnace where the Zn is volatilized with the waste gas. Many Cu slags contain 30–40% Fe and a modified Strategic-Udy plant is being constructed to deal with these. Ni and Cr ores are also considered, ferronickel resulting from the Strategic-Udy and Ugine processes.—C.H.

**A device for investigation of the conditions in the tuyere zone** W. Żołkowski (*Hutnik*, 1961, **28**, (1), 22–25) A description of a penetrometer coupled with a dynamometer and driven by an electric motor is followed by a diagram according to which under normal operating conditions the depth reached should be roughly proportional to the load. If the blast-furnace investigated was running well, the load of 80 kg could push the rod 1 m deeper than when it was running cold.

**Factors affecting the production and properties of foundry pig iron** L. Éles (*Koh. Lapok-Öntöde*, 1960, **11**, Nov., 248–255) The main factors affecting the production and properties of foundry pig iron, such as the chemical composition of ores, the amount and composition of slag in the blast-furnace, the temp. of blast, the method and temp. of casting, and the rate of cooling are discussed by the author.

**Utilization of nickel in smelting pig iron from ores containing alloying elements** A. B. Glovatskii and G. I. Chasovitin (*Stal'*, 1961, (3), 207–209) Nickel is lost as carbonyl and this can be minimized by reducing CO content in the upper part of the furnace and increasing top temperature.

**Temperature and composition of pig iron in the eroded part of a blast-furnace hearth pad** N. N. Babarykin, I. M. Galemin, and L. A. Lepikhin (*Stal'*, 1961, (3), 198–200) Metal was tapped from a furnace through additional tap holes at different levels and salamanders were sampled. The whole scheme of sampling with temp. recording is detailed. Mixing is shown to be very slow at the hearth pad, the iron existing in distinct layers and penetration of the concrete occurs early. The composition of the salamander depends on its rate of cooling.

**Observations on the wear of the refractory linings of the stacks of blast-furnaces using sinter** C. Pastor and J. Laborne (*Rev. Mét.*, 1961, **58**, Jan., 25–37) A detailed investigation is described, of the operation of 11 blast-furnaces where this trouble was experienced. It was concluded that blowing conditions rather than the refractories were responsible; the effect of cooling conditions was also examined.

**A consideration of the instrumentation of blast-furnaces** J. Garcia Moreda (*Inst. Hierro Acero*, 1960, **8**, Oct.-Dec., 817–834) [In Spanish] The function of the control instruments on the furnace, stoves, gas cleaners, and general equipment is explained and evaluated as an integral part of the process.—P.S.

**Granulation of liquid iron: Stewart and Lloyd's process** H. E. Storr and T. Rudkin (*Iron Coal Trades Rev.*, 1961, **182**, March 24, 613–618) The principle of granulating liquid iron by pouring it into water is not new but the danger of explosion hazard and the means of removing the product prevented its development. The present method is described. The advantages of granulated iron are that a small site area is required, the cost of the installation is only 60% of a pig-casting machine, remelting fuel in the blast-furnace is much reduced, wear and tear of transporting equipment and of blast-furnace charging equipment is considerably reduced, the material is easier to handle mechanically, maintenance of plant is much less and the cost of producing granulated iron is about ½ of that of machine-cast pig iron. Perhaps the only real disadvantage is that the granules retain more moisture and to deal with this careful control is required. The results obtained at four plants now operating this process show that any disadvantages can be readily overcome.—C.V.

**Chicago Congress on the reduction of iron ores (3–5 May, 1960)** J. Astier (*Rev. Mét.*, 1961, **58**, Jan., 3–11) A report of the 23 papers read at the Congress (30 refs).

**Low-sulphur reducing agents for use in the Krupp-Renn process** B. Tejnický (*Hutn. Listy*, 1961, **16**, (1), 3–7) [In Czech] On the basis of experimental and theoretical considerations it is concluded that partly coked South Bohemian lignite of low sulphur content is most suitable for the preparation of sinter charges for blast-furnaces.—P.F.

**Alternative iron making processes** (*Min. J.*, 1961, **256**, Jan. 20, 65, 67) The different fuels and the alternative methods of effecting reduction are summarized and briefly discussed. Where ores can be pre-reduced, power requirements are greatly diminished with increased furnace output; this is the basis for the DLM, Electrokemisk, Strategic-Udy, and Orcarb processes. The Wiberg process (Sweden) produces sponge iron and the Stelling process is somewhat similar. The Krupp-Renn and RN processes use solid fuel, with or without auxiliary gas or oil. In the former, low-grade ore is used but a high-S metal results. The latter works at a lower and more closely-controlled temp. and a lower S-metal results. A pilot plant is in operation in the USA but no commercial installation has yet been built. The Freeman process uses pellets from high-grade ore with low temperature coke and oil for the burner giving high-grade iron pellets for the production of Fe powder. The Sturtzelberg process deals with ores having a recoverable Zn content, the Basset (Denmark) works with a very basic mix producing a cement clinker as well as Fe, the Hoganas (Sweden) effects reduction in ceramic saggers in a tunnel kiln giving Fe for production of powder. The Hyl (Mexico) uses natural gas giving sponge-Fe 90% reduced and the H-iron process uses the same fuel or coke oven gas partially oxidized and then subjected to a water-gas shift reaction. The ERL and Nu Iron processes are also mentioned; these have been developed to the pilot stage.—C.V.

**Back pressure and various injections: experience gained on the international low-shaft furnace at Liége** E. Bonnaure (*Rev. Mét.*,1961,, **58**, Jan., 13–24) The drawbacks of the low-shaft furnace are first reviewed, e.g. high coke rate caused by a decrease in the proportion of indirect reduction; increase of throat temp., and a tendency to too ready fluidization. Remedies proposed are: improved burden preparation, use of high back-pressure in the throat, and injection via the tuyeres of materials such as fuel oil with oxygen-enriched blast, and other similar measures. Trials carried out are described (13 refs).

**Process made feasible by sale of both iron and slag** Quebec Iron and Titanium Corp. (*Steel*, 1961, **148**, March 13, 123–124) An unusual reduction process, using as starting material mixed ilmenite and hematite ore, upgraded in Humphrey spirals, then charged in reducing furnaces, with iron and slag tapped separately, is reported. Most of the iron is recovered as metal, the slag, containing part of the iron and all the titanium, is sold to producers of Ti pigments, and Ti metal. The process is described.—S.H.-S.

**Production of pearlitic grey iron in the electric furnace** N. G. Chakrabarti, U. K. Bhattacharya, B. K. Gupta, and N. R. Mitra (*IGK Kongress Vorträge*, 27th International Foundry Congress, Zurich, 1960, 223–236) [In English] Operating details are given of the manufacture of automobile components to DIN GG–26, and the manufacture from a single base iron of medium and light castings in the electric furnace of Tata Locomotive and Engineering Co., Bihar. The metallurgical control adopted for the production of castings with uniform machining properties is also described.

## PROPERTIES, TREATMENT AND USE OF SLAGS

**Chemical properties and structure of liquid slags** A. Staronka (*Hutnik*, 1961, **28**, (1), 1–6) Liquid slags resemble aqueous solutions, their cations and anions being metallic ions and more or less polymerized silicon dioxide respectively. This concept of liquid slags has been confirmed by investigation of their properties such as electrical conductivity, cryoscopic properties, surface tension, density, and thermal expansion.

**Influence of the slag in iron making** G. Col (*Inst. Hierro Acero*, 1960, **8**, Oct.–Dec., 861–870) [In Spanish] A theory is proposed which suggests that the slag can have a reducing effect, through intermediate reactions, when making iron by reduction of its oxide. The theory, which is applied to the fusion-reduction process, the Lubatti process, and to the quality and quantity of metal produced, shows that the final reduction of the oxide is completed in the slag through the following reactions: $2CaSiO_3 + 2C = Ca_2SiO_4 + 2CO + Si$ and $Ca_2SiO_4 + Si + FeO = 2CaSiO_3 + 2\,Fe$.—P.S.

**Structure and properties of the slags of metal smelting processes. II. Viscosity measurements on melts of the systems ferrous oxide–lime–silica and ferrous oxide–lime–alumina–silica** P. Röntgen, H. Winterhager, and R. Kammel (*Z. Erz. Met.*, 1960, **13**, Aug., 363–373) A survey of the literature on the viscosity of CaO, FeO, and $SiO_2$-containing melts is followed by a report on some viscosity measurements in the systems CaO–FeO–$SiO_2$, CaO–FeO, FeO–$SiO_2$–anorthite, FeO–CaO·$SiO_2$–anorthite, and FeO–CaO.$SiO_2$–gehlenite (47 refs).

**Phase relationships in non-condensed oxide systems** B. A. Sidebottom and J. White (*Trans. Brit. Ceram. Soc.*, 1961, **60**, Feb., 96–123) Attention is drawn to the use of simple thermodynamic relationships to predict probable phase distributions in ternary systems containing oxides which represent different valency states of the component metals. The principles involved are restated and the phenomenon of 'recurrent melting' in non-condensed systems is described.—S.H.-S.

**Activities in lime–alumina melts** R. A. Sharma and F. D. Richardson (*JISI*, 1961, **198**, Aug., 386–390) [This issue].

**Activities in the system CaO–MgO–$Al_2O_3$** M. R. Kalyanram and H. B. Bell (*Trans. Brit. Ceram. Soc.*, 1961, **60**, Feb., 135–146) The activity of lime in melts in the system CaO–MgO–$Al_2O_3$ at 1500°C have been determined by measuring the sulphur equilibrium between a CO–$CO_2$–$SO_2$ gas mixture and the melt and relating this to the same equilibrium with a lime-saturated slag. Using the phase diagram for the CaO–MgO–$Al_2O_3$ system and thermodynamic data for calcium aluminate, tentative isoactivity lines for $Al_2O_3$ have been drawn.

## PRODUCTION OF STEEL

**Furnace construction and maintenance simplified with integrated combustion and control system** (*Indust. Heat.*, 1961, **28**, Jan., 102–104, 158) The completely integrated and balanced combustion system designed by North American Mgf. Co. depends on light-weight fuel–air ratio and furnace-pressure controllers. Normally the fuel is primary and air secondary.—K.E.J.

**Furnace instrumentation today** W. J. Swinn (*Brit. Steel*, 1960, **26**, Oct., 339–342, 359) A review of the field of furnace instrumentation in the steel industry; problem of measurement, programming, and automatic control are discussed with examples.

**How to store stainless steel** Carpenter Steel Co. (*Iron Age*, 1960, **186**, Nov. 10, 186) Designs for divide bins, and paint, tilt, and storage racks for stainless steel are presented, with recommendations for suitable materials for racks and safeguards against moisture, and other physical damage.—S.H.-S.

**High purity oxygen helps produce high quality steel in the USA** G. Kreis (*Alloys Met. Rev.*, 1961, **2**, March, 6–8) A brief review of the origins and sequence of the basic oxygen process is presented.—S.H.-S.

**The use of oxygen in steelmaking** (*Fonderia*, 1961, **10**, Jan., 23–26) [In Italian] Various techniques are briefly described including the LD process, use in OH furnaces, the Kaldo and Rotor processes concluding with a comparison of the advantages and disadvantages of these methods.

**Basic Oxygen steelmaking** J. E. Tredennick (*Indust. Heat.*, 1961, **28**, Feb., 301–310) Data are given for the process at Kaiser Steel Corp's Fontana works, including calculation of the charge blowing, requirements, methods for controlling composition (C, Mn, P, and S), and various operational developments.—K.E.J.

**New features at two continental steelworks** C. W. J. Crawford (*Iron Coal Trades Rev.*,

1961, **182,** Feb. 24, 413–414) At Louvroil a materials storage and blending tower is being constructed; from this tower any desired order or amount (nine different ores and two grades of coke) can be dispensed and it has ample capacity for supplying three modern blast-furnaces of 6·5 m hearth dia. The automatic control equipment will be able to accept burdening programmes for the three furnaces dispatching the various feeds for each furnace without the assistance of a human operator. The blast-furnace used in the initial trials had hearth dia. 4·5 m, eight tuyeres, useful volume 500 $m^3$, and details of the burden are given. Light and heavy fuel oil has been, or will be used but it has already been decided that some form of fuel injection will be employed in the new furnaces. A new OLP converter plant on the Saar is also discussed; this (30-t) is refining iron of 1·8%P with one slagging-off in a tap-to-tap time of ¾ h. The performance is well up to expectation and the results from the 60-t OLP converter at Denain and the 140-t unit at Dunkirk are awaited with interest; this latter is to work on hematite iron.—C.V.

**Steel in India** M. D. J. Brisby and J. Dobie (*Engineer*, 1961, **211,** Feb. 10, 202–205) Three large new steelworks, Durgapur, Rourkela, and Bhilai, of British, German, and Russian construction, respectively, now nearing completion in India, are discussed, and the economic viewpoint of the need for using existing capacity and slowing down capital expenditure relative to India's financial resources is suggested.—S.H.-S.

**The new Ougrée steelworks of the Société Cockerill-Ougrée—Introduction** M. Grosjean (*Rev. Univ. Mines*, 1960, **103,** Nov., 453–454) An outline of the layout of the new Ougree basic Bessemer works put into operation in Aug. 1959.

**The new Ougrée steelworks of the Société Cockerill-Ougrée. General layout of the steel-works** R. Maas (*Rev. Univ. Mines*, 1960, **103,** Nov., 455–459) The layout of the iron mixers, scrap supply, stocking of other raw materials, the conveyor belt supply system, the design of the 50–60 t converters, and the charging and tapping of the converters are outlined.

**The new Ougrée steelworks of the Société Cockerill-Ougree. The control of basic Bessemer operation** P. Flament (*Rev. Univ. Mines*, 1960, **103,** Nov., 463–480) The use of calculators to simplify the control of the basic Bessemer blows is described in its application to the Ougrée works.

**Experience with deoxidation tests in the basic Bessemer converter by injection of carbon** W. Küntscher and G. Richau (*Neue Hütte*, 1961, **6,** Feb., 78–81) [In German] Results of tests are analysed, the test procedure explained and the economic aspects are discussed.

**The development of the LD process in recent years** H. Trenkler (*Bol. ABM*, 1961, **17,** Jan., 15–44) [In Portuguese] The writer indicates that developments in the last two or three years have been based on the following lines of attack: (i) application of the process to high-phosphorus pig iron, (ii) adaptation to available raw materials, (iii) increase of the application to making high-carbon and alloy steels, (iv) adaptation to large and small firms, and (v) improvement of the understanding of the metallurgy and discusses each theme in turn (13 refs).—P.S.

**The operation of a small LD converter and its application to the refining of nickeliferous pig iron** E. Franco and J. C. Correa da Silva (*Bol. ABM*, 1961, **17,** Jan., 45–58) [In Portuguese] The equipment and technique for processing charges of 20 or 200 kg are described and the experimental data is discussed. It is concluded that even very small-scale refining of common and special pig irons is possible, the equipment can be very simple. It is possible to obtain ferro-nickel (up to 30%Ni in the trials reported) with only a small nickel loss to the slag.—P.S.

**Fuel and power required for making steel in the LD process** K. Rösner and F. Dobrowsky (*J. Inst. Fuel*, 1961, **34,** Jan., 3–7) A series of mathematical calculations based on an assumed pig iron of the usual steelmaking analysis, with other assumptions representing empirical values typical for running practice in existing LD shops. Figs.1 and 2 show heat flow according to the paper's calculations, which conforms to results obtained in running practice.—S.H.-S.

**OLP Process** IRSID (*Tecn. Indust.*, 1961, **39,** Jan., 64–68) [In Spanish] A description of the operation and metallurgy of the process is provided.—P.S.

**Basic oxygen steel** (*Kaiser Steel Corp.*, pamphlet, pp.15) This process is described: 17 basic oxygen furnaces are now in operation on the North American continent and the essential steps are reviewed and the inherent advantages are briefly listed.—C.V.

**Operation of the oxygen-steam blown converters at the VLN steel plant of The Steel Company of Wales Ltd** M. C. Harrison and P. Truscott (*JISI*, 1961, **198,** Aug., 341–352) [This issue].

## PRODUCTION OF FERRO-ALLOYS

**Ferroalloys** H. A. Tucker (*US Bur. Mines, Bull.*, 1960, (585), 291–304) The producers of ferro-alloys in the USA are listed; the nature of the alloys produced is indicated (FeMn, SiMn, FeSi, FeP, etc.). The various outstanding problems are reviewed: the structure and operation of furnaces to deal with these, the assurance of an adequate and dependable domestic supply and the waste of ferroalloying elements in plant residues and the utilization of scrap. It is also pointed out that there is an accumulation of unsold ferrophosphorus at the rate of 16500 t per year for which new uses and markets are required.—C.V.

**Improving the smelting technique for ferro-boron** P. F. Snezhko and I. V. Lugovtsev (*Stal'*, 1961, (3), 239) Improvement of ferroboron production by the aluminothermic process is described. Better calcination of the borate with greater reduction of moisture content and flushing of the slag with molten iron droplets raise the extraction from 45 to 70% of the B.

**Silchromosol—the new alloy for making 'Corten' steel** Union Carbide Ltd (*Alloys Met. Rev.*, 1961, **2,** March, 9–10) The Silchromosol alloy, a resin bonded mixture of a finely divided ferro-alloy, containing 50%Cr and 25%Si, formed into cylindrical briquettes approx. 2in dia. and 1¼in high is presented with a brief description of its properties and uses.—S.H.-S.

## FOUNDRY PRACTICE

**The 27th International Foundry Congress** (*Koh. Lapok-Öntöde*, 1960, **11,** Dec., 265–276) This paper is a report of the proceedings of the 27th International Foundry Congress held between the 18th and 24th September 1960 in Zürich.—P.K.

**Casting? Forging? Machining from solid? Cheapest way to produce metal parts** H. Kee (*Prod. Eng.*, 1961, **32,** March 27, 60–61) The data given are based on cost estimates given by 30 companies for two representative parts. Tooling cost is small when runs exceed 25 000; casting is cheapest for production runs but this may be offset by machining when required tolerances are closer than those given by sand castings; for a single part, machining from the solid is cheapest; die castings from brass, Al, and Zn are discussed; other factors are also briefly examined.—C.V.

**Iron castings in construction** B. Thyberg (*Tek. Tidskr.*, 1960, **90,** Nov. 18, 1149–1154) Topics dealt with include: castings *v.* welding or forging, machineability, and examples of the use of iron castings (12 refs).

**Steels for investment casting** (*Eng. Mat. Des., Data Sheet No.*51, 1960, **3,** Dec., 787) The difficulties encountered with BS.3100 are noted and the data relating to BS.3146 are tabulated.

**Centrifugal casting of heavy steel castings** J. Bahna (*Slévárenství*, 1960, **8,** (12), 432–435) The principles of the centrifugal casting method applied to heavy castings are discussed with special reference to its utilization in the production of thick-walled tubes in the Voroshilov Works in Slovakia. It is recommended that the method should also be used in the production of other heavy castings, e.g. for roller tables in rolling mills, for bi-metal tubes, etc.—P.F.

**Centrifugally cast steel tubing properties and applications** E. D. McCauley (*Mod. Castings*, 1960, **38,** Dec., 56–65) The methods of centrifugal casting used in production are critically discussed, and a new method of casting that combines the best of various other techniques is described. By the use of this method, higher speeds than normal have been used, without hot-tearing and cracking.

**Casting grey cast-iron cylinder sleeves into rotating moulds** J. Ptáčník (*Slévárenství*, 1960, **8,** (12), 419–427) On the basis of detailed experimental work and a theoretical analysis of heat transfer problems arising in the casting of the cylinder linings, it is shown that sound castings are obtainable by rotating the moulds, which may be of the pre-heated metal or of the sand type, depending upon the complexity of the sleeves.—P.F.

**New pipe plant meets needs of changing market** R. H. Herrmann (*Foundry*, 1960, **88,** June, 100–105) The conversion of a plant previously used for casting railway car wheels to the production of centrifugally cast iron pipe is discussed, with economic reasons for the change, and a short description of the new plant operation with a diagram of layout.

**'Cloud Nine'—permanent mould casting of steel** S. I. Smolensky, N. N. Guglin, G. F. Zasetskii, A. K. Provornyi, V. A. Tutev (*Mod. Castings*, 1961, **39,** Feb., 40–43) The permanent casting of large steel castings using steel moulds, developed in Russia, is described. It has been possible to get results that are better than those obtained from cast-iron moulds.

**Two casting processes team up to improve foundry efficiency** Lebanon Steel Foundry (*Iron Age*, 1960, **186,** Dec. 1, 130–131) For turning out precision castings in conventional and special-purpose alloy steels, a combined system, using ceramic-shell moulds (which are cheap and easy to make) and investment wax moulds (much more costly but more accurate), is used within a simple casting. The method, its operation, and results, are briefly described.

**Solidification of metals: A summary** W. K. Bock (*Mod. Castings*, 1960, **38,** Dec., 87–91) The theory of solidification is discussed, and the ways in which this knowledge may be used to produce the required structure in a casting are indicated.

**Factors affecting soundness in alloys with long and short freezing range** J. T. Berry and T. Watmough (*Mod. Castings*, 1961, **39,** Jan., 63–74) After a brief discussion of mould material and casting alloy variables, two problems are studied. First, the extent of the influence of mould material upon the feeding requirements of three short freezing range alloys (0·2% steel, grey eutectic cast iron, and a 13%Si–Al alloy). Second, the effect of applied pressure to the feeder head of castings made in various long freezing range alloys.

**Factors affecting metal-mould reactions** G. A. Colligan, L. H. Van Vlack, and R. A. Flinn (*Mod. Castings*, 1961, **39,** Jan., 104–110) The effect of Mn additions and of atmosphere on the interface reaction have been investigated. A practical means of minimizing metal-mould reactions may be possible through the use of organic sand binders and additives that control the interface atmosphere.

**Methods of overcoming heat cracks and shrinkage porosity in malleable castings** W. H. Baxter (*Inst. Brit. Found. Aust.*, 1960, **11,** 87–97) Heat cracks and shrinkage porosity are well known as defects which cause a large percentage of the casting rejection in the malleable foundry. The defects and their causes are listed and methods developed in the author's foundry to overcome them are illustrated and discussed in detail.—C.F.C.

**Foundry experience of the pinhole defect in cast iron** J. V. Dawson (*BCIRA J.*, 1960, **8,** Nov., 805–811) Pinholing is usually associated with the presence of traces of Al which increase $H_2$ pickup. Tests are described and recommendations for dealing with outbreaks of the defect are given.

**Influence of grain size and stripping time on the incidence of hot tearing in white iron castings** M. D. Twitty (*BCIRA J.*, 1960, **8,** Nov., 844–856) A 30%Cr-iron was used to simplify grain size control and tearing diminished as grain size decreased. Small amounts of Ti had a considerable influence, larger amounts had less effect on grain size but still further reduced susceptibility to tearing. Tests on white iron were also made relating tearing to time in the mould before stripping.

**How to cut noise in the cleaning room** W. O. Hanson (*Foundry*, 1960, July, 76–80) A series of measures whereby a foundry cleaning room, using air blast cleaning, four tumbling barrels, grinding and other operations, abated noise levels substantially and at a reasonable cost is reported with supporting data.—S.H.-S.

**Good lighting boosts product quality** J. L. Tugman (*Foundry*, 1960, **88,** July, 115) Improvements, not so much in increased production, as in a drop in spoilage and rejected parts, resulting from the installation of two-lamp fluorescent units over moulding stations, with nearly 200 foot-candles of illumination for machine operators, are briefly described.

**Characteristics of the distribution of dust particles in the foundry** S. Yabuuchi, S. Hujimori, and T. Yamaguchi (*Imono*, 1960, **32,** April, 280–286) The average size, and size distribution of dust particles was studied, and the type of distribution in relation to the position of the point of dust formation was determined.

**Accident prevention in the smaller foundry** M. N. Hallett (*Ironfounding Health and Safety* 1960, 52–55) The type of accident (cut, strain, burn of foot, leg injured by falling object, burn in eye, particle in eye, miscellaneous) is analysed for two factories engaged in making light castings and the causes and implications are examined.—C.V.

## VACUUM METALLURGY

**The contribution of the vacuum technique to metallurgy** D. A. Degras (*Rev. Mét.*, 1960, **57,** Sept., 805–813) The techniques used in degassing, melting, and metal treatment and the properties of vacuum-treated metals are reviewed (13 refs).

**Review of book 'Production of steel and castings under vacuum' by D. G. Lyubetskii (Mashgiz, Kiev, 1959, pp.174)** V. F. Polyakov (*Stal'*, 1961, (2), 127).

**Treatment of steel in vacuum** L. Bangert (*Proc. First International Congress on Vacuum Techniques*, 1958, June, 577–587; from *Nucl. Sci. Abs.*, 1960, **14,** Nov. 15, 2832) Outgassing and vacuum melting are considered as examples.

**Vacuum treatment of molten steel. A new way of improving converter steel production** A. M. Samarin and L. M. Novik (*Proc. First International Congress on Vacuum Techniques*, 1958, June, 588–592; from *Nucl. Sci. Abs.*, 1960, **14,** Nov. 15, 2832) USSR experience with vacuum treatment of Bessemer steel is described.

**Vacuum plant for steel degassing** J. I. T. Green and D. M. Hayes (*Iron Coal Trades Rev.*, 1960, **181,** Oct. 14, 827–832) Various methods of producing high vacuum for degassing steel during or after melting are examined, information being given about types of pumps and steam ejectors commercially available and some degassing plants now in operation being compared. The three most commonly used mechanical pumps are described. While it is shown that suitable mechanical pumps are available, it is recommended that for large degassing plants steam ejectors should be used.

**Theoretical and practical aspects of vacuum induction melting of high-strength steels** P. S. Schaffer (*PB* 161928, 1960, March, pp.74; *Rept. No. RPL* 10/17; from *US Res. Rep.*, 1960, **34,** Nov. 18, 624) Optimum procedures were worked out to obtain properties so far unattained in 4340 steel castings. Removal of gases, inclusions *in vacuo* is considered and great improvements in ductility and toughness resulted.—C.F.C.

**Vacuum arc upgrades steel alloys** P. A. Archibald (*Steel*, 1960, **147,** Nov. 7, 107) A new, consumable electrode, vacuum arc remelt furnace producing super-strength steels and alloys, with improvement in physical properties and reduction in size and number of non-metallic inclusions is briefly described.

**Future looks favourable for vacuum steel making** D. C. Ludwigson and A. M. Hall (*Steel*, 1960, **147,** Nov. 7, 106–107) Various advantages from vacuum methods of melting and degassing in larger heats in steelmaking are presented and briefly discussed.—S.H.-S.

**Vacuum induction melting high strength steels** P. S. Schaffer, P. J. Ahearn, and M. C. Flemings (*Mod. Castings*, 1960, **38,** Oct., 95–112) Crucible-melt reactions, deoxidation, desulphurization, degasification, dissociation, and volatilization are considered, and the improvements in properties caused by vacuum melting are discussed.

**Crucible Steel starts new vacuum degassing unit at Midland Works** (*Iron Steel Eng.*, 1961, **38,** Jan., 183–184) The Heraeus-Ruhrstahl siphon, Bochumer-Verein (three-modifications) and the Dortmund-Huttenunion processes were studied. The outstanding advantages of the latter are the more complete mixing with more complete degassing and the provision for adding alloying elements under vacuum; this process has been adopted; the operation is described. The cost is considered, but the potential savings are the elimination of a long slow cooling cycle, increasing yield through improved cleanliness and less use of alloying elements since, these being added in the absence of oxygen, oxidation is avoided.

**Cyclic, vacuum degassing unit is evaluated at Crucible** W. E. Gregg (*Steel*, 1960, **147,** Dec. 19, 122–123) The operation of a cyclic, vacuum degassing unit at the Midland (Pa.) works of Crucible Steel Co. of America, is described and its advantages reported.—S.H.-S.

**The outgassing of steel by vacuum irradiation. New results and developments** A. Tix and W. Coupette (*Proc. First International Congress on Vacuum Techniques*, 1958, June, 562–567; from *Nucl. Sci. Abs.*, 1960, **14,** Nov. 15, 2832) The Bochumer Verein process is described and it is suggested that the mechanism is stepwise.

**Reaction course in vacuum outgassing of molten steel** O. Winkler and T. Kraus (*Proc. First International Congress on Vacuum Techniques*, 1958, June, 568–570; from *Nucl. Sci. Abs.*, 1960, **14,** Nov. 15, 2832) A study of the rate-determining factors in vacuum outgassing and inert gas flushing is reported.

**Improvement of Cr–Ni–Mo iron base alloys by vacuum melting and casting** F. J. Gillig (*Rept. No.KA–1289–M–6*; *PB* 148243; from *US Res. Rep.*, 1960, **34,** Oct. 14, 477) The object of this programme was to investigate the effects of minor changes in composition and vacuum melting on the high temp. mechanical properties of iron base alloys containing 20Cr–20Ni–5Mo and various minor additions of Nb, W, Ti, B, and Al. Twenty-one heats were cast with varying compositions. The 100-h rupture strength at 1500°F was used as the basis for rating the elevated temp. strength. The strength of the base line heat was not surpassed by any appreciable amount but equivalent strengths were obtained with several compositions that are leaner in alloying elements.—R.S.F.C.

**Vacuum bright annealing in elevated furnaces** Warbrick (Eng. Specialities) Ltd (*Wire Ind.*, 1960, **27,** Oct., 985–987) The method of annealing under high vacuum in elevated furnaces developed by Braun Angott of Hagen, W. Germany in which all oxygen is kept away from the material to be annealed, particularly tubes of very narrow interior dia., which, due to evaporated lubricants being completely drawn off, leave the furnace in a perfectly bright condition both inside and out, are described, and practical and economic advantages are considered.—S.H.-S.

**Bright annealing in overhead high-vacuum furnaces** E. Schwarz (*Draht*, 1960, **11,** Nov., 710–713) An annealing plant is described in which the high-vacuum furnace is of overhead construction. The advantages offered by this type of furnace are pointed out. The control equipment of this high-vacuum plant is also described.—T.G.

**Heat treatment under artificial vacuum** W. Herdieckerhoff (*Wire Ind.*, 1960, **27,** June, 593–596, 616) The article refers mainly to Cr–Ni alloys but steel wire and strip annealing and descaling are briefly considered.

## REHEATING FURNACES AND SOAKING PITS

**Forge furnace takes minimum space but handles king sized ingots** P. H. Lessard (*Steel*, 1960, **147,** Dec. 26, 62–63) An automatic furnace pressure control system using high-velocity burners and dampers mounted in the roof directly over the burners, to ensure uniform heat, eliminating the need for double walls, is presented, and its operation described.

**Furnace now handles 40 per cent more work** International Nickel Co. Inc. (*Steel*, 1960, **147,** Dec. 12, 82–83) A series of improvements in design and equipment leading to increased reheating furnace production is described.

**A general review of heat recovery in furnaces** H. B. Weston (*Glass Techn.*, 1960, **1,** Oct., 187–190) The general problem of heat loss and heat recovery in industrial processes is discussed in general terms. Some mention of steel forging and rolling is included.

**The influence of sulphur in fuels used in reheating furnaces on steel quality** F. Wiesner and E. Tichopadova (*Hutn. Listy*, 1960, **15,** (12), 923–939) The literature relating to the subject is reviewed. Laboratory and works experiments with various liquid fuels confirmed that sulphur enters the surface layer of steels, and that the effect is more pronounced in reducing than in oxidizing atmospheres. Oil 'M' containing 3%S is suitable for use in reheating furnaces only for mild steels or the silicon steels used for transformer sheet.—F.F.

**Influence of sulphur in heavy oil used for an ingot-reheating furnace on rolling** T. Mori and M. Kamakura (*Tetsu to Hagane*, 1960, **46,** Nov., 1533–1538) Full-scale tests showed that high-S oil fuel produced more scale which became sticky. Increasing the oxidizing activity of the furnace atmosphere prevented the development of stickiness. Atmosphere control was effective in removing these effects.

## HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

**Technical progress and the problem of costs in the heat-treatment of steel** K. Gielewski and J. Zgorzelniak (*Przeglad Mechaniczny*, 1959, **24,** 798–800; from *Polish Techn. Abs.*, 1960, (2), 41) A comparative analysis of three methods of heat-treatment of the same elements with a view to proving the importance of selecting appropriate heat-treatment methods as a factor in reducing costs and improving quality. The appropriate tests were made in one of the industrial works.—R.S.F.C.

**Unit couples heat-treating steps** R. W. McIntyre (*Iron Age*, 1961, **187,** Jan. 12, 70) An automated heat-treat unit, combining heating, quenching, and tempering of 4-lb to 20-lb size sledge-hammer heads in a single and simple operation, with output of 125 pieces per h, is described.—S.H.-S.

**Mean free path in problems of acoustic and thermal radiation** C. Codegone (**Atti della Accad. delle Sci. di Torino*, 1954–55, **89,** 66–67) An extended definition of mean free path for use in such problems is produced.

**Experiments on the thermal radiation from flames** C. Codegone (**Atti della Accad. delle Sci. di Torino*, 1954–55, **89,** 345–349) An expression advanced previously was confirmed by work on a jet engine flame.

**Heat transfer and fuel-fired industrial furnaces** P.-O. Strandell (*Tek. Tidsk.*, 1960, **90,** May 13, 543–550) Heat transfer in the furnace, rate of heating, temp. differences in the heated material, thermal stresses, the reactions of the surface of the material with the furnace atmosphere, and applications of rapid heating are discussed (17 refs).

**Heat-treatment of steels. I. Heat-treatment methods** L. F. Spencer (*Mach. Design*, 1960, **32,** Dec. 8, 160–167) The function of the different elements in steel is recapitulated, transformation curves are presented, and hardenability is discussed. The effect of austenitic grain size on the various properties of steel is listed.—C.V.

**Heat-treatment of pearlitic malleable castings** (*Foundry*, 1960, **88,** April, 98–101) This article is a reprint of a chapter from *Malleable Iron Castings*, the new handbook of the Malleable Iron Founders Society, and discusses the effect of the heat-treating cycle on pearlitic malleable iron, with an analysis of commercial processes for its production, both unalloyed and alloyed.—S.H.-S.

**The estimation of the optimal heat-treatment of cast carbon steel with 0·5% carbon from its resistance to dry friction abrasive wear** T. Sala and J. Rutkowski (*Prz. Odlew.*, 1961, **11,** (1), 12–22) Heat-treated samples were tested on

Amsler machine against not heat-treated standard steel samples and the best conditions for this kind of test have been found. These seemed to depend on crystallographic structure of the samples. Cast steel samples have been more worn out by softer standard steel samples other conditions being the same.

**Which heat-treatment for AM350 and AM355** (*Mat. Design Eng.*, 1960, **52**, Dec., 110–112, 145) The various properties resulting from the heat-treatments indicated are tabulated and discussed.—C.V.

**Heat-treatment for nodular graphite cast steel** S. Fujita and S. Mutsumine (*Toyota Engng.*, 1960, **12**, Sept., 112–119; from *Japan Sci. Rev. Mech. Elect. Eng.*, 1960, **7**, Nov., 430) [No abstract].—C.F.C.

**Heat-treating electrical steels . . . why all the mystery?** J. J. Lawless, jun. (*Metalw. Prod.*, 1961, **105**, Jan. 11, 56–58) It is stressed that even a slight variation of one alloy constituent in an electrical steel can have a marked effect on the heat-treating procedure. A plea is made for a set of rules relating to heat-treatment that will enable the gap between scientific theory and production actualities to be bridged. Examples are given.—C.V.

**Straightening by means of heat and its introduction into series production** B. Vrána (*Zvárania*, 1960, **9**, (12), 362–364) The rectification of deformation arising in steel sheet or in tools as a consequence of quenching or welding is discussed. Four specific cases are reviewed.

**Suit the atmosphere to the job** Englehard Industries Ltd (*Metalw. Prod.*, 1961, **105**, Jan. 4, 61) The Nitroneal generator, producing a nitrogen–hydrogen gas mixture by reacting $NH_3$ with air in the presence of a Pt-group metal catalyst, is described. It is available in two sizes supplying up to 500 and 1500 $ft^3/h$ and as the reaction is exothermic no heat or power is required. The generator is illustrated and examples are given of its performance.

**Specialized heat-treating cuts die costs** D. F. Griffin (*Metalw. Prodn.*, 1960, **104**, Dec. 28, 53–56) Six requirements for die materials are fatigue resistance, high yield strength, wear resistance, high hardness, low movement and distortion and uniform carbide distribution. Salt baths, controlled atmosphere, sub-zero treatment, furnace construction, operating temp., and movement of the trays are discussed and the operating procedure is described. It is considered that although the endothermic $NH_3$ atmosphere is 5–10 times higher in cost, the increase is justified in relation to the improvement in die quality.—C.V.

**Die casting die steels heat-treatment and related problems** D. R. Edgerton and N. O. Kates (*Mod. Castings*, 1960, **38**, Nov., 73–87) The choice, quality, and heat-treatment of die steels, including nitriding, structures for machining, and available furnace types are reviewed. Types of failure of dies are described, explained, and illustrated.

**Isothermal hardening and its applications** (*Mét. Constr. Mécan.*, 1960, **92**, Dec., 1013–1021) The transformation diagram and its applications are presented and isothermal hardening and tempering are discussed. An isothermal hardening furnace is described, and special treatments and the process of isothermal annealing are explained and discussed.

**Modern continuous belt furnaces harden many different parts at high production rates** H. L. Hopkins (*Wire Wire Prod.*, 1960, **35**, May, 620, 648).

**The mechanism of hardening in 17–7 PH stainless steel** E. E. Underwood and A. E. Austin (*BMI Rept. on kinetics of Internal Structural Changes*, 1960, June, pp.54; *WADD Techn. Rep.*, 60–236; *PB* 161850; from *US Res. Rep.*, 1960, **34**, Oct. 14, 476) Studies on commercial sheet of 17–7 PH steel and on single crystals of Fe–17Cr–7Ni–2Al were examined. Acicular particles in large numbers gave the hardness level; ordering was apparently absent from quenched single crystals, but appeared on ageing. Neutron diffraction suggested an ordered bcc structure with Fe on one sublattice and Cr, Ni, and Al distributed on the other.

**Supplement for the investigation of high frequency induction surface-hardening of low carbon steel** H. Nishimura, K. Fujii, and O. Kyotani (*Suiyokwai-Shi*, 1960, **14**, Aug., 160–163) To clarify the reason of the existence of the second hardened layer found on the inner boundary of high frequency induction-hardened low-C steel, specimens of 0·05%C steel were quenched at various temp. above 700°C and their hardness was measured. In this experiment the hardness was found to increase in α-crystals, this may be due to their age-hardening when saturated with C. By tempering them, the hardness decreases with time. The authors conclude that further investigation is necessary to clarify the phenomena more distinctly.—C.F.C.

**Attachments make induction hardener universal** (*Metalw. Prod.*, 1961, **105**, Jan. 11, 63–64) Four alternative interchangeable work-handling attachments are described. A six-station indexing table is shown which enables the Delapena HSV300 machine to be used in automatic lines in conjunction with a conveyor or vibratory bowl feed and automatic loading or as a semi-automatic fixture for manual operation. It is suitable for hardening, of small cylindrical, spherical, or conical parts on a high production basis. With a shaft hardening attachment, components up to 15·75in long and 9·45in wide can be heated with, or without, rotation. There is provision for initial pre-heating dwell before each heating traverse and fast traverse between heating zones.—C.F.

**On the outer layer of the cyaniding case. (Fundamental study on cyaniding and carbo-nitriding, 5th Report** )F. Yoshikawa (*Nippon Kinzoku*, 1960, **24**, (6), 339–343) Using a specimen cyanided at 780°C for 15 h and having a comparatively thick outer layer, the qualities of the layer were mainly investigated. It was confirmed that the outer layer consists of a compound layer and a composite layer contained compound and solid solution. It was found that the partial extinction in the cementite diffraction patterns is due to the existence of martensite, and definition of the term 'outer layer' is given. Also, the carbo-nitriding diagram of this case was decided, and the correlation of the diagram with the thermal changes of the case was explained.

**Confirmation of the effect of enrichment by benzene vapour of protective petroleum gas on the decarburization of tool steels during annealing** V. F. Ivanov (*Stal'*, 1961, (1), 73) A note from Novosibirsk. Use of $>140$ $g/m^3$ prevents decarburization. $CO_2$ falls from 8·2–6% and CO increases from 11 to 19·2%.

**Gaseous annealing of malleable castings** C. G. W. Overton (*Iron Steel Rev.*, 1960, **4**, Dec., 31–36) Malleable, blackheart, pearlitic blackheart, and whiteheart castings, gaseous annealed, are discussed and the equipment and and plant required is summarized.—C.V.

**Continuous annealing of tin plate** R. A. McClure (*Reg. Tech. Meet. AISI*, 1958, 239–252) Essentially, the Gary Sheet and Tin Mill is described. It stands 60 ft above floor level and 30 ft underground with a floor space 350 ft × 50 ft and contains a half mile of threaded strip in the line in the various loops, furnace passes, etc. The usual range of tin mill product thicknesses and widths (0·0075 to 0·015in and 18 to 37in) are taken at speeds up to 1000 fpm, the rated capacity being 30 t/h at this speed for 0·01in × 30in strip. The layout of the charging and the heat-treatment portion of the line is shown and details of each section are provided. In such a system tracking problems can seriously affect operating speed and production. These are solved by proper roll balance, alignment, and the use of specially contoured rolls in certain sections of the line, the use of the Lorig centering roll, ahead of the furnace, being of considerable help in the maintenance of good tracking.—C.V.

**Is it bright annealed, or else?** G. J. McManus (*Iron Age*, 1960, **186**, Dec. 15, 78–79) The use of bright annealing on stainless strip for the automotive industry is discussed and the trend towards its general adoption is briefly reviewed.—S.H.-S.

**Effect of low-temperature annealing on cold-rolled sheets of 17–7PH stainless steel** K. Murakawa (*J. Aeron. Res. Inst. Univ. Tokyo*, 1960, **2**, Sept., 105–109; from *Japan Sci. Rev. Mech. Elect. Eng.*, 1960, **7**, Nov., 429) The recently improved 17–7PH stainless steel sheets were examined for the effect of annealing at temp. in the neighbourhood of 475°C; the residual bending stress $\Delta\theta_{90}$ and the Vickers hardness number were measured. The plot of the minimum value of $\Delta\theta_{90}$ versus percentage of cold reduction shows that the material is uniform and that the spring characteristics of 17–7PH stainless sheet is excellent. The precipitated particles were examined by means of the electron microscope, and no appreciable directionality of the precipitates could be detected.—C.F.C.

**Study of the mechanism of stress relief in alloy and plain-carbon steels by annealing** M. Kroneis (*Schweisstechn.*, 1960, **14**, Nov., 126–128) Helical springs were made of a number of steels varying from plain-carbon to high-alloy steels. The springs were heat-treated to the required mechanical properties. The springs were then compressed and annealed in the compressed state at various temp. and for various periods. The 'springback' after annealing and releasing from the compression tool was used as a yardstick for the degree of stress-relief. The results obtained are discussed with special reference to the effect of alloying additions.—T.G.

**Fabrication and annealing factors affecting grain size of 18Cr8Ni–Ti superheater materials in steam boilers** F. Eberle and J. S. Makris (*Trans. ASME*, 1960, **82D**, Dec., 855–866) The effect of cold deformations in tube and superheater fabrication and of temp. and time of annealing on the grain-size characteristics of 18Cr8Ni–Ti is shown by laboratory tests with material from six heats of steel, when cold-drawn tubing retains a uniform small grain size at annealing temp. up to 1900°F–1950°F, above which temp. individual grains begin to grow at an accelerated rate, leading to a mixed grain structure. Extension of exposure to 30 min produced noticeably larger grain structure. Observations suggested that materials with high Ti/C ratios may retain predominantly small grain size at annealing temp. as high as 2050°F.—S.H.-S.

**Annealing equipment for the malleable iron foundry** B. A. Ruediger (*Foundry*, 1960, **88**, Dec., 85–89) Various types of malleable annealing furnaces, including elevator, bell, roller hearth, and pusher furnaces, and their operation, are described and discussed. The processing of pearlitic malleable iron and the economics of different classes of furnace are tabulated and analysed; periodic, batch, and continuous furnaces are compared economically; and the cost of reheating, oil quench, and air draw equipment, and operating expense is presented and compared in detail.—S.H.-S.

**Some experiments in controlled low temperature stress relief** R. N. Parkins (*Brit. Weld. J.*, 1961, **8**, Jan., 24–29) The Linde process was applied to welded mild steel pipes in which the transverse residual stresses were high. Stress-corrosion tests and stress analyses indicated that such stresses may be reduced by this process.

**A new method for increasing yield point of structural steel** E. R. Parker (*Reg. Tech. Meet. AISI*, 1958, 295–305) The influence of certain impurities, ferritic grain size strain rate, etc. on upper and lower yield points is summarized and the introduction, under carefully controlled conditions, of a substructure is considered. This is produced by cold working and annealing at a temp. 900–1300°F and the presence of this substructure does not necessarily have any deleterious effect on the notch brittleness of the steel. Using an AISI 1020 steel which in the annealed condition had an upper yield point of 54000 psi and a lower yield point of 47000 psi it was found that the tensile strength was 67000 psi and the elongation 2in. When the same material was strained to 8%, the yield points disappeared and the ultimate strength was raised to 73000, the elongation being reduced to only 6%. When a similar specimen was strained to the same extent but in addition was heated to 1275°F (to relieve the work-hardening and to develop a substructure prior to testing) the upper yield-point was raised to 76300 psi, the lower to 64000 psi and the ultimate strength to 77000 psi, the elongation being 22%. These results provide convincing evidence that other processes than those involved in annealing had

occurred during the heating; it can be argued that these changes were not those of simple strain ageing as this process is associated with reduced ductility since the elongation was increased by heating to a value almost equal to that of the original annealed material.—C.V.

**Investigations carried out on the corrosion of lead vats** M. Buch (*Wire World Internat.*, 1960, **2**, Dec., 280–292) Lead baths used for annealing drawn wire showed corrosion of the steel vats. Materials and heating methods are recommended.

**Fluidized bed: new approach to rapid heat-treating** C. L. Kobrin (*Iron Age*, 1960, **186**, Oct. 13, 81–83) A fluid-bed furnace, giving faster production and improved product quality and permitting the performance of a number of precise heating and quenching cycles, and, when a run is over, requiring no conventional cleaning treatment is described, with three major parameters for its setting up: particles, gas, and system. Information as to its operation and data collected from many test runs are presented.—S.H.-S.

**Fluidized beds: new heat-treating medium** General Electric Co. (*Metalw. Prod.*, 1961, **105**, Feb. 1, 56) Work is heated in a dense dispersion of hot, highly-turbulent refractory particles which are kept in suspension by a controlled stream of gas. This fluidized bed thus provides fast heat-transfer and is also suitable for intermediate (and variable) quench rates.—C.V.

**Finishing facilities at Consett** (*Iron Steel*, 1961, **34**, Feb., 60–62) Owing to special demands, a complete plate normalizing, quenching, and tempering section was built to which plates could be fed from the unfinished plate-handling and loading bay. This was however arranged so that the treated plates could be routed back to the shearing lines should this be necessary; the layout is shown. The pressure quench equipment, the oil-fired continuous plate normalizing furnace, and other equipment are indicated and discussed.—C.V.

**Fast heating accomplishes uniform spheroidizing of headed stock** J. Tschopp (*Blast Furn. Steel Plant*, 1961, **49**, Feb., 184–185) A modern, continuous, pusher-type furnace is described; this is used for spheroidizing the coil stock and consistently produces >85% spheroidizing of pearlite in the structure of SAE–1038, 1041, and several low-alloy steels. The furnace has six temp. zones and the degree of uniformity attained is such that only spot sampling is required.—C.V.

**The effect of flow rate on the cooling ability of liquid for steel quenching** M. Tagaya and I. Tamura (*Osaka Univ. Fac. Eng. Techn. Rep.*, 1960, **10**, Oct., 797–804) The effect of flow rate in turbulent streams on the cooling ability of water and three sorts of oil were quantitatively examined. The cooling ability of liquid increased with the Reynolds no. and is given as a function of Reynolds no. and Prandtl's no. This relationship would make a foundation for designing a quench tank and its agitation system (17 refs).—C.F.C.

**Chilling behaviour of a roll-type cast iron** K. E. Pinnow and R. W. Lindsay (*Mod. Castings*, 1961, **39**, Jan., 75–84) The effect of superheating temp., pouring temp., and charge material variations on the chill characteristics of a roll type cast iron were studied by means of chill castings made from melts of constant chemical composition.

**Heat-treatment of steels. II. Steel selection** L. F. Spencer (*Mach. Design*, 1960, **32**, Dec. 22, 120–125) Tables are given showing the relation between dia. and as-quenched hardness and the effect of mass on mechanical properties of 1340, 3140, 4140, 4340, 4640, 5140, and 8740 steels oil quenched and tempered at 1000, 1100, and 1200°F. Carbon and alloy steel characteristics are also discussed and a considerable further volume of data is presented.

**Influence of heat-treatment on transformation in Kh17N7Yu steel** E. G. Fel'dgandler and M. V. Pridantsev (*Stal'*, 1961, (1), 58–64) Effects of tempering time and temp., Al content, and effects of isothermal holding are determined and the mechanisms involved are discussed.

**Effect of silicon on the tempering of high strength steels** C. J. Altstetter (*Massachusetts Inst. Tech., Abstracts of Theses*, 1958–1959, 71) AISI 43XX steels (up to 3%Si) were studied measuring longitudinal mechanical properties and kinetic behaviour. This was performed after isothermal tempering (72–850°F) and mechanical properties were evaluated after 1 h tempers (room temp. to 1300°F). Si affects the temp. at which first-stage decomposition products transform to cementite and ferrite although Si has no marked effect on this stage itself. In Si-free steels, transformation of low-C martensite and epsilon carbide to ferrite and cementite (the third stage in Fe–C alloys) is divided into two parts on account of the stabilizing effect of alloying elements on $\epsilon$ carbide. The third stage is the transformation of low-C martensite to thin plate cementite and ferrite while the final reaction is the resolution of the $\epsilon$-carbide and precipitation of cementite. In Si steels these two reactions occur simultaneously because of the higher transformation temp. The changes in the matrix and carbide phases are discussed. It is also shown that the increase in as-quenched hardness with 3%Si is more marked at low C levels and the 500°F embrittlement is attributed to the morphology of the first-formed cementite and not to the loss of C from the matrix. In the second tempering stage (transformation of austenite to bainite) a retardation is found with Si additions.—C.V.

## FORGING, DRAWING, STAMPING AND PRESSING

**Cold forging of steels** F. Griffiths (*Iron Coal Trades Rev.*, 1961, **182**, Jan. 13, 87–89) The chief development engineer of the British Motor Corporation Ltd, based on the Corporation's experience, recommends that in the cold forming of steels the work should be carried out on hydraulic and not on mechanical presses, and presents economic data in support of his thesis.—S.H.-S.

**Cold forging of steel** (*Auto Eng.*, 1960, **50**, Dec., 539–452) Work by Cold Forging Ltd is described and illustrated, with a literature survey.

**Basic features of the cold forging process** A. M. Cooper (*Wire Ind.*, 1960, **27**, Dec., 1189–1194) A study of the cold forging process, with a description of machines, the sequence of operations, cold forging limitations, extrusion, underhead forging, radii, and points, is presented.—S.H.-S.

**Press selection for cold forging** H. D. Feldman (*Metalw. Prod.*, 1961, **105**, Jan. 11, 51–55) A discussion. Cold header, knuckle joint, crank, and hydraulic presses are examined and suggestions are offered to overcome their shortcomings.—C.V.

**How BMC approached cold forming** F. Griffiths (*Metalw. Prod.*, 1960, **104**, Nov. 30, 63–67) Experience in the development of cold forming processes for steel, producing various small components, is reported.

**Cold forging gun barrel rifling** L. R. Beesly (*Metalw. Prod.*, 1960, **104**, Nov. 16, 63–66) The present practice is summarized and a new forming process used at the Royal Small Arms factory at Enfield is described, the machine used being of Austrian origin specially tooled. A vertical cold forging machine squeezes the workpiece between a number of hammers having a predetermined stroke and position; the resultant cross-section depends on the number and shape of these hammers and on the rotation of the workpiece. A profiled mandrel is then used rotating independently. The base contains a forging box incorporating four hammers; each is positively controlled and individually driven and mounted on this base are two vertical columns supporting a crosshead containing the upper gearbox which controls the vertical movement of the chucking head. Mounted on this crosshead is a vertical hydraulic cylinder which correctly positions and retracts the forging mandrel. The chucking head, guided by slideways, feeds downwards during the forging. A spring loaded mechanism in the chuck caters for the interrupted motion caused by the forging action and a hydraulic cylinder axially aligned with the workpiece controls vertical movement centralizing the component beneath the hammers. The radical position of the hammers is varied hydraulically to permit limited variation in external dia. such as tapering. Production methods are compared and the advantages of this method are indicated. However, some development and experience with this machine is still required.—C.V.

**Giant forging press lifts size limits of closed die forgings** H. Allen and J. W. Brougher (*Iron Age*, 1961, **187**, Jan. 12, 66–67) A large closed-die press, part of a 20000 t capacity unit, handling stainless steels, Mo, Ta, W, Nb, and other alloys, totally enclosing the hot billet within the main dies, with only one heat to complete a forging and giving high physical properties and grain uniformity, is briefly described. Vertical extrusions up to 30 ft long and 56in dia. are also produced by it.—S.H.-S.

**Tools for heavy forging work** R. C. Benson and R. J. H. Hunt (*JISI*, 1961, **198**, Aug., 390–401) [This issue].

**The mechanics of explosive forming** W. S. Hollis (*Metalw. Prod.*, 1960, **104**, Nov. 16, 75–77) With explosive forming processes, there is a relative absence of springback and work hardening, this being due to the uniformity of loading and the rate of strain application. An analysis is presented to the changes that take place within the material during the change of shape, it being show that with explosive forming the variation of stress and strain is brought about by the propagation of elastic and plastic waves and initiation of particle velocity throughout the material. This process is entirely different from the gradually applied load where the stress and strain condition is established evenly and progressively. Since impulsive waves are reflected, the material can be subjected alternatively to compressive and tensile stresses under impulsive loading; this does not occur under static loading.

**Explosive deformation** D. A. de Fremery (*Metalen*, 1961, **16**, Jan. 16, 13–14) This article deals briefly with experiments that have already been conducted in the USA and Russia with a view to deforming sheet materials by utilizing the extremely powerful forces exerted for minute fractions of seconds by cartridges containing high exposoives such as dynamite and TNT either in air or under water. There is also reference to the explosive effects of powdered metals and sparks from electric discharges. The possibilities of the practical applications of such forces are discussed although it is emphasized that at present the idea is only in its very early stages and a great amount of further experimental work is still essential before any definite conclusions can be reached.—F.R.H.

**'Bubble' tank cuts costs at explosive forming plant** Lockheed Aircraft Corp. (*Steel*, 1960, **147**, Nov. 7, 120) A method devised by Lockheed Aircraft Corp. for installing large forming tanks above ground, using a curtain of compressed air bubbles inside walls of the forming tank, with construction essentials, is described, with operation and results.—S.H.-S.

**Vibratory finishers for deburring** Lord Chemical Corp. (*Prod. Fin.*, 1960, **25**, 84–86) A brief, general description. Steel stampings and non-ferrous parts are treated.—C.V.

**Spinning techniques for stainless steel** J. M. Henderson (*Can. Metalw.*, 1960, **23**, Sept., 44–46) Stainless steel can be spun into cone angles as small as 30° from flat blanks by the displacement method and excellent surface finishes can be achieved by burnishing. The relative spinning properties of seven stainless steels are given for shallow and deep spinning and approx. spinning speeds for Cr–Ni steels (blank dia. 3—>50in) are shown in rpm and peripheral speeds. The combination of high working pressures, extreme deformation, and close machine control not only produces parts with increased strength and hardness but with better fatigue strength. Very close tolerances can be attained with high quality surface finish; low tooling cost, reduced scrap loss, and the ability to produce complex shapes in conical contours results in economical forming.

**The influence of straightening on the relaxation of wire for prestressed reinforced concrete** V. I. Kokhno (*Stal'*, 1961, (1), 82–84) Hand straightening strengthens the wire and reduces relaxation but the scatter of the properties of the wire increases. Machine straightening

weakens the wire and increases relaxation but the resulting scatter is less.

**The effects of temper rolling and strain ageing on the formability of low-carbon steel** D. V. Wilson, R. D. Butler, and B. B. Moreton (*JISI*, 1961, **198**, Aug., 376–386) [This issue].

**Operation bootstrap aids wire plant** D. Schmid and R. Cubbler (*Steel*, 1960, **147**, Dec. 5, 117–118) New equipment installed by the staff and a 100% increase in plant investment in six years is briefly discussed.—S.H.-S.

**Quality control in the wire industry: Part 2** E. F. Jubb (*Wire Ind.*, 1960, **27**, Dec., 1211–1212, 1217) The results of the tests described in Part I are summarized and the various controls discussed for wire drawing, with applications to galvanizing, annealing, patenting, etc., netting and fence production, nails, cut lengths, etc., with a final reference to packaging and length/weight ratios.—S.H.-S.

**The fundamentals of wire drawing. 4. Slip on wire drawing machines** C. P. Bernhoeft (*Wire Ind.*, 1960, **27**, Oct., 1007–1009) The fourth instalment of a book concerned with the drawing of Al with examples and statistics, together with much information of a general nature on slip machines and the loss of power through slip is presented and examined. **Part 6. Profile of a drawing wire** (Dec., 1197–1198) The diagram of a profile with die nib and die shape is presented and described and its operation discussed mathematically, with a table of die angles, area reductions, height of drawing cone, surfaces, and volumes and tabulated explanations for four items in mm and in. **VIII. Die pull** (1961, **28**, Feb., 166–167, 169) A summarized presentation of the salient problems relating to Al and Al–alloy.—C.V.

**Observations upon production planning and control in a steel wire mill. II** D. W. Bedford (*Wire Ind.*, 1961, **28**, Feb., 175–176, 179) A general review of the many problems of successful integration between the several departments both on the production and administrative sides.—C.V.

**Wet wire drawing** J. K. Annandale (*Wire Wire Prod.*, 1960, **35**, May, 607–610, 654–655) The process and the machines used are described with the properties of the wire.

**Wire mill production planning and control** F. Wilcox (*Wire Wire Prod.*, 1960, **35**, June, 729, 731, 732, 778) Method used in keeping records of the passage of materials through the various stages of production are outlined.

**A new wire temperature meter** G. McH. Sturgeon (*Wire Wire Prod.*, 1960, **35**, June, 721–723, 787) Work by BISRA on accurate assessment of wire temp. during processing is reported. The Addison meter is described.

**Tooling for cold steel extrusion** M. D. Verson (*Metalw. Prod.*, 1961, **105**, Feb. 1, 49–53) The terms 'cold forging' and 'cold extrusion' are clearly defined. The selection of the correct press is considered and the tool steels to be used are tabulated showing the forging, annealing, preheating, hardening, and tempering temperatures.—C.V.

**True deformation during extrusion** J. Buffet and B. Jaoul (*Rev. Mét.*, 1960, **57**, Sept., 827–833) The effect of the parasitic deformation caused by tool friction on the additional work done, and the relationship of extrusion pressure to lubrication conditions are discussed.

**What factors influence design of glass-extruded steel?** J. H. Rice and F. C. Hacket (*Iron Age*, 1960, **186**, Dec. 22, 59–61) The increasing industrial applications of steel extrusions, where shapes are difficult to roll or where short production runs are called for, and present development work on the glass extrusion process aimed at improving surfaces and giving more tolerance control, with variables of the extrusion process from one metal to another, are described and discussed.—S.H.-S.

**The phosphate-coating and lubricating of steel for cold extrusion** D. James (*Machinery*, 1961, **98**, Jan. 11, 84–90) The reactions taking place are discussed and it is shown that essentially the coating consists of $Zn(PO_4)_2$. $4H_2O$ which usually exists in the orthorhombic form. The characteristics of this coating are compared and the reason for its superiority is discussed. The processing sequence is shown and notes are provided to illustrate each stage. (Jan. 18, 137–139) A brief review of plant and processes.—C.V.

## ROLLING MILL PRACTICE

**Rolling mills** D. N. Chatterjee, S. C. Dasgupta, and P. H. Tata (*TISCO*, 1960, **7**, April, 79–171) A very detailed account of the history, developments, present plant, and likely future expansion of the Tata rolling mills is given. A wealth of diagrams and photographs is provided.

**On the question of specialization of rolling mills** B. G. Fastovskii (*Stal'*, 1961, (1), 79–81) Inter-regional economics are considered and where demand exceeds supply it is suggested that production of the more difficult sections should be stopped. Increased productivity by increasing ingot size as well as shorter working days make these sections still less desirable.

**Forces, moments and stresses in rolling mills. An investigation of vibration** R. Liebold (**Freiberger Forschungsh. Met.*, 1960, (48), 5–25) An elaborate calculation of vibration effects is presented and discussed. A simplified rolling train model is used in the derivation.

**The neutral angle in hot and cold rolling processes** Z. Wusatowski (**Archiwum Gornictwa i Hutnictwa*, 1955, **3**, (1), 11–42) The assumptions on which the various equations were derived are given and a comparison is made to decide which gives the values closest to those actually measured. The choice depends in practice on the conditions and on the accuracy required.

**The effect of temperature at the end of hot rolling on the mechanical properties of medium-alloy sheets of steel grades 40, 45 and 50** V. F. Ivanov (*Stal'*, 1961, (1), 73) A note from Novosibirsk. For GOST 914–56 and 4041–48 the upper temp. limit at the end of rolling need not be restricted. With 1577–42 this temp. should be below 800°C and, if normalized, 880°.

**Establishing an industry standard for the variation in the width of hot rolled mill edge carbon steel sheets** D. H. W. Allan (*Reg. Tech. Meet. AISI*, 1958, 449–462) A statistical study in which a number of mills participated. The following data were required: (1) width measurements to $\pm\frac{1}{16}$in at 20 positions along the length of each coil, readings to be spaced at intervals of ~5% of the coil length; (2) a series of 20 such measurements to be made on five coils from each day's product for 30 days for a total of 150 coils; (3) data collection to be for ⩽30 working days and preferably ⩾90 calendar days; (4) product to be measured, hot rolled mill edge C-steel sheets, 0·25% max C, widths 12in to 90in inclusive produced on a continuous strip mill.—C.V.

**Developments in electrical equipment for reversing plate mills** H. S. Brown and A. P. Baines (*English Elect. J.*, 1960, **16**, Dec., 32–54) Essentially the same as *JISI*, 1960, **194**, Feb., 225–240.

**Motorized lifting device simplifies sheet stacking** Inland Steel Co. (*Steel*, 1960, **147**, Oct. 3, 75) A motorized, rack and pinion type sheet lifter controlled by push button from a cab, and with a crane follower to align the lifter with the stack, is described.

**New techniques in mill control give better hot strip** R. J. Moran and H. N. Snively (*Iron Steel Eng.*, 1961, **38**, Jan., 107–116) It is estimated that a hot strip mill rolling 2 million tons/year may have scrap and off-gauge losses as low as 1%, yet even this is 20000 t. The control of gauge before the slab is reduced to $\frac{1}{2}$in is not satisfactory but in the reversing rougher it is possible to ensure that slabs of consistent thickness are delivered to the finishing mill. The first step in automatic control is here introduced using a punched card preset screw-down control defining a definite programme; schedules also can be rapidly changed. Two alternatives are suggested for the passing through a crop shear. The second eliminates the major cause of cobbling as a certain length is cropped from the slab whether it is required or not. Automatic gauge control for the finishing mill is described in some detail and the question of data logging is discussed.—C.V.

**The production of hot-rolled wide strip** H. Winterkamp (*Bändar-Bleche-Rohre*, 1960, Sept., 3–8) This is the first part of a series on the production of hot-rolled wide strip dealing with soaking pits, the blooming mill, and the surface treatment (flame scarfing) of the slabs. Finally pusher-type furnaces are described.

**Production of cold-rolled wide steel strip** A. Honců (*Hutník*, 1960, **10**, 386–390) Production technology and types of reversing and tandem mills best suited for maximum productivity are critically surveyed, with special reference to Czechoslovak conditions.—P.F.

**Heating the rolls in the finishing train of the wide strip mill** A. P. Chekmarev, M. M. Saf'yan, V. M. Meleshko, L. N. Soroko, and V. P. Kholodnyi (*Stal'*, 1961, (1), 43–46) Various advantages are derived from induction heating of the rolls up to the temp. at which rolling can begin. The stress conditions of a surface-heated roll are investigated and in practice less fractures of the rolls in the initial stages were encountered.

**Experience gained in the slitting of strip** H. Schröer (*Bänder-Bleche-Rohre*, 1960, Sept., 18–23) The author gives a very detailed account of the machinery used for slitting strip, steel, stainless steel, and non-ferrous metals, as well as of the mode of operation with particular reference to accuracy in width and edge quality which has recently been greatly improved by the use of neoprene distance pieces between the rotary knives.—T.G.

**Automatic grinder line upgrades stainless strip** Republic Steel Corp. (*Steel*, 1960, **147**, Nov. 21, 116–117) An automatic strip grinding line having four features: (1) tip to tip grinding and polishing of coiled stock; (2) selective spot grinding of localized areas; (3) variable line speeds to control stock removal; (4) a back-up (billy) roll that permits handling stock 0·018 to 0·187in thick, with its operation and special features, is described.—S.H.-S.

**Abrasive belts remove crown from stainless steel strip** W. N. Redstreake (*Iron Age*, 1960, **186**, Oct. 27, 89–91) Abrasive-belt machines in tandem grinding in oil are described, which remove the 'crown' from stainless steel strip up to 28in wide, producing truly flat strip which is now rolled finished to 0·001in, ±3%, meeting tolerances for aircraft, missile, and space vehicles.—S.H.-S.

**Designing grooves for tube sections** A. K. Shurupov (*Stal'*, 1961, (1), 54–56) Methods for calculating and defining elliptical and oval sections are given.

**New line boosting pipe plant output** (*Steel*, 1960, **147**, Nov. 14, 112–113) The Steelton (Pa.) mill of Bethlehem Steel Co. is being equipped with a line to plane, form, weld, expand, and test 40 ft pipeline sections with a capacity of 25000 t of pipe a month. The equipment and its operation is briefly described.—S.H.-S.

**Largest pipe mill goes into operation** (*Metalw. Prod.*, 1960, **104**, Nov. 9, 82) The Big Inch Pipe Corp. Ltd, (Ogden, Canada), has put into operation a continuous pipe mill 600 ft long; this is designed to manufacture large dia., high strength transmission pipe from 18in to 36in OD with wall thickness from $\frac{1}{4}$–$\frac{3}{4}$in. It can be operated by five or six men as compared with the 18 or more which are required to operate a conventional mill. It produces 60 ft lengths and is claimed to be the largest mill of its kind in the world.—C.V.

**Tube production and processing** H. Grave (*Bänder-Bleche-Rohre*, 1960, Sept., 9–13) The production of seamless tubes by the conventional processes is briefly described. The treatise is extended by descriptions of the pusher bench process, by extrusion and various reduction processes.—T.G.

**Manufacture of weldless steel tubes** (*Edgar Allen News*, 1960, **39**, Nov., 241–245) A brief illustrated description.—C.V.

**The manufacture and inspection of seamless steel tubes. II** G. S. Marshall (*Quality Eng.*, 1960, **24**, Nov.–Dec., 166–173) Various tests are outlined. A large section treats of non-destructive methods including ultrasonic methods.

**Helical rolling is the answer, say Soviets** (*Metalw. Prod.*, 1960, **104**, Nov. 2, 80–81) Continuous rolling of circular-section components of varying cross-sectional area, to compensate for shortage of steel bar production, is briefly described, with examples of different types of equipment and their operation.—S.H.-S.

**Improving the internal surface of pipes by reducing the increase in the outside diameter when piercing** E. A. Svetlitskii and B. I. Mindlin (*Stal'*, 1961, (1), 56) Improved dimensioning of roll forms is given. Reducing the

outside dia. in the first operation improves internal surface with increase in output. Reduction in two piercing operations saves material.

**Steeltubing—its weight? Its annular area?** F. Kaplan (*Prod. Eng.*, 1960, **31**, Dec. 26, 59) A nomograph is given.

## MACHINERY AND SERVICES FOR IRON AND STEEL PLANT

**Marshalling railway wagons electronically** (*Overseas Eng.*, 1960, **34**, Sept., 44–45) A brief description of the yard at Margam, South Wales, is given. Twelve reception and 50 sorting sidings cover most of the 178 acre site. The wagons are examined and by selective uncoupling are divided into 'cuts' according to destinations and the information is passed to the control tower by lightweight portable radio transmitter as to the number of wagons and required siding. This information is set up on punched paper tape and three page printers. The tape passes through a tape reader connected to the control panel and the electric signals describing the first four cuts are fed into storage units and indicators on the panel are energized. Facilities are provided for cancelling or correcting the destinations of any of the four cuts displayed. As each cut is dealt with, the remaining ones are moved up and the vacated storage is refilled.—C.V.

**Tensometric weighing on cranes in the metallurgical industry** M. Hajduk and A. Burda (*Hutn. Listy*, 1960, **15**, (10), 765–771) The scope and limitations of weighing on cranes are discussed, and the principles utilized are considered, with special reference to Czechoslovak conditions.—P.F.

**Electronic weighing in steelworks. Its application in a modern LD plant** C. P. A. de Meer (*Iron Coal Trades Rev.*, 1961, **182**, Jan. 20, 121–126) The successful development and use of load cell weighing equipment for all weighing in the modern plant of the Royal Netherlands Blast Furnace and Steelworks is described.—S.H.-S.

**Lightweight design of overhead travelling cranes** H. Ernst (*VDIZ*, 1960, **102**, Aug., 1089–1094) Features of lightweight design, with particular reference to welded construction in light metal are discussed.

**Transport of ingots by travelling cranes feeding steelworks pits** K. Schmoll (*Acier Stahl Steel*, 1960, **25**, Dec., 520–522) With plans and illustrations of crane and grab systems.

**Steelworks gas distribution** D. N. Gwyther (*Year Book Coke Oven Man. Assoc.*, 1960, 469–485) By comparison with the gas industry, the steel industry holds small stocks of gas; the cost and problems of storage are indicated and the types of gas holder are briefly reviewed. Instrumentation (flow measurement, temp., pressure, and calorific value), gas sampling, transmission, and gas control are summarized.

**Electrical power distribution** K. S. Kuka and B. K. Sen (*TISCO*, 1960, **7**, April, 172–186) The planning and designing of the electrical power distribution system for the TISCO steelworks under the Two Million Ton plan are discussed.

**Development and co-ordination at an integrated iron and steel works and a gas grid supply station for the utilization of coke oven gas** J. T. Davies, W. F. Edwards, W. D. Rees, and H. J. Victory (*Year Book Coke Oven Man. Assoc.*, 1959, 434–487) The relationship between coke-oven gas suppliers and gas undertakings in the early days is outlined and the transition to the present co-ordination attained by the Steel Company of Wales and the Wales Gas Board. Details as to the working out of this project, the agreements entered into, quality calorific value, area of distribution, layout of the Aberavon gas works at different stages of the development, graphs of coke-oven gas received and town gas distributed (1940–1957), weekly load curve of gas availability at Aberavon (1957–1958), a diagrammatic arrangement of the distribution of the principal fuels, etc., are given, and discussed at some length. This interchangeability of fuels ensures that there is an adequate, uninterrupted supply of heat to all work processes and also gives a flow of coke-oven gas to the Aberavon Gas Works without provision of a very large holder storage.—C.V.

**Power engineering** S. N. Sircar, A. K. Roy, and N. J. Dastur (*TISCO*, 1960, **7**, April, 187–197) The previous power facilities are discussed, and the adjustments required due to the Two Million Ton programme are described.

**Theory and practice in recovery of flue dust and mill scale** R. D. Hoak and H. C. Bramer (*Reg. Tech. Meet. AISI*, 1958, 61–79) An empirical equation has been evolved which gives a sedimentation index: this however is somewhat unwieldy and is simplified to: $SI = 2{\cdot}426L^{1{\cdot}33}.W^{2{\cdot}0}.D^{2{\cdot}33}\ (2D+W)/Q^{3{\cdot}67}$ where SI = sedimentation index, min., L = effective pit length, ft, W = effective pit width, ft, D = effective pit depth, ft, and Q = water rate, $ft^3$/min. Specific examples are given. The relationship of dredging cost to scale recovery is considered. In one case cost of daily dredging was only 25% over the weekly figure but 200 t of scale was recovered. The dependability of the equation is stressed since the data for a long flume holding 50 gal fits the equation as well as that from scale pits holding 30 000 gal.

## WELDING AND FLAME CUTTING

**Welding in the Soviet Union** (*Iron Coa Trades Rev.*, 1960, **181**, Oct. 21, 895–896) A brief account of the visit of a party from the British Welding Research Association to five institutes and a welding exhibition in Russia, with particular reference to friction welding and diffusion welding processes now being operated in that country.—S.H.-S.

**Gas-shielded arc welding** P. Sjöman (*Svetsaren*, 1960, **25**, (2), 40–55) Underlying principles, the ESAB equipment, welding of Al and light alloys, weld properties, and types of joint are among the topics discussed.

**Arc welding in a gaseous atmosphere** P. Sjöman (*ESAB Rev.*, 1960, (3–4), 17–33) A review of materials, procedures, and equipment for different types of weld, with the economics and limitations of the method.

**Welding of alloy steel to unalloyed steel** J. Björkroth (*Dansk Tekn. Tidsskr.*, 1960, **84**, July, 151–158) An account of the welding of stainless steel to low alloy and plain C steel, the welding of martensitic Cr steel and stainless steel cladding is given.

**Electroslag welding of grade 20GS steel** V. M. Semenov (*Lit. Proizv.*, 1958, (10), 21–23) Steel 20GS in the forged and cast state and its electrolsag welding with various electrode wires was investigated. It is expected shortly to replace steel 35 in welded-forged and welded-cast structures. Its mechanical properties and weldability are better than those of steel 35.—A.I.P.

**How good is the electro-slag process?** H. H. Thomasson (*Canad. Metalw.*, 1960, **23**, Oct., 32–34) The Soviet electro-slag welding process, which is limited to thick materials, with welding speeds claimed to be faster than those of other processes, is analysed and described with mathematical analysis and reference tables based on personal observation. A comparison table for multiple-pass arc welding with electro-slag welding for 4in steel plate is presented, and a diagrammatic sketch of the electro-slag process showing copper slides, molten weld metal, and the molten slag being fed by three current-carrying electrodes is shown, also a photograph of a machine of the Arcos Corp. welding heavy steel sections in the upright position.—S.H.-S.

**Plant for electroslag welding of boiler drums** O. Hajzler (*Zváranie*, 1960, **9**, (10), 294–295) Plant installed on a test basis in the Klement Gottwald Steelworks in Ostrava showed several inadequacies. Reconstruction on the basis of Soviet blue-prints appertaining to long-established automatic welding plants is described.—P.F.

**How friction welding joins bar stock and tubing** R. R. Irving (*Iron Age*, 1960, **186**, Dec. 29, 47–49) A compact friction welding unit, which produces high-quality welds on metals, plastics, and even ceramics in a fraction of a minute and which welds dissimilar materials and diverse ranges of metals and plastics, by the use of sliding friction is described, and numerous fields for its industrial use are presented.—S.H.-S.

**$CO_2$ welding—are the Belgians right?** H. H. Thomasson (*Can. Metalw.*, 1960, **23**, Sept., 29–32) Belgian practice is discussed in connexion with the view that single wire submerged melt welding is obsolete. It is claimed that with $CO_2$, the visible arc gives better control and placement of deposited metal, that the cost of $CO_2$ shielding is less than for the granular melt, that there is a greater ease in starting and the $CO_2$ deposit has low $H_2$-content. The absence of spatter, even with high current values, is most advantageous and although the electrodes contributed to this, voltage control was the essential factor. Examples of the automatic welding of storage tanks are illustrated and discussed together with the continuous welding of girth seams with one pass each side in plates of thickness 0·24 to 0·88in. Current in amp. (ext. and int.), welding speed in in/min, and weight in lb of rod used per ft weld.—C.V.

**Application of flame fluxing with acetylene, town gas and propane** L. S. Wade (*Weld. J.*, 1960, **39**, July, 711–715) The advantages of the flame fluxing method are discussed, and applications in which it can and cannot be used are described.

**Metal-arc welding of stainless steels** M. C. T. Bystram (*Edgar Allen News*, 1960, **39**, Nov., 253–256) A general summary. The composition and applications of selected austenitic stainless steels is given and the Murex electrodes required are indicated. Details of the finishing of these steels are tabulated. Some of the operational difficulties associated with the welding of thin stainless sheet are overcome when it is used as a lining for mild steel or in the case of fabrication made from stainless clad material; the heavier backing gives mechanical strength and dissipates heat without necessarily adding greatly to the cost of manufacture.—C.V.

**Experience gained in Sigma welding with 'Coxogen'** S. Hausotter (*Schweisstechn.*, 1960, **14**, Nov., 128–131) Porosity of the weld is one of the greatest obstacles in the Sigma welding of plain-carbon steels. A new gas mixture of undisclosed composition marketed under the name of 'Coxogen' avoids porosity in sigma weldin, of these steels. The modificatious required in edge preparation and welding practice when using Coxogen are described.—T.G.

**Operating practice with Arcair torch** N. J. Krumm (*Foundry*, 1960, **88**, April, 164–172) The use of the torch, which combines electric arc melting of metal with simultaneous removal of molten metal by a high-velocity air jet, and its application on a variety of materials from steel to nonferrous alloys is discussed, with data on its operation in removing risers and pads, at times difficult to attack by other methods.

**Principles of template preparation for the oxygen cutting process** L. M. Layden (*Weld. J.*, 1961, **40**, Jan., 34–40) Electronic tracing devices for control of flame-cutting machines are described and discussed as of two types, according to the kind of template required: edge tracers for a template forming the outline of the part by a silhouette, and, secondly, line tracers capable of following a pencil or ink line. Scanning principles and operating principles related to the techniques of template preparation for each system are discussed. Various factors influencing the final accuracy of the cut part, and the relative advantages of the two types of tracer are presented.—S.H.-S.

**Automatic height control for oxygen profiling machine** Hancock & Co. Ltd (*Process Control Autom.*, 1960, **7**, Nov., 586) The addition to the Hancoline oxygen profiling machine of a height control system consisting of a small electronic control unit which ensures that burners maintain a constant height above the plate during cutting is briefly described.

## MACHINING AND MACHINABILITY

**The Boeing organization for numerically-controlled machinery** (*Machinery*, 1960, **97**, Oct. 12, 820–828) Equipment at the Wichita, Ken., works of Boeing Airplane Co. for production of the B-52 Stratofortress is described, with tape preparation and techniques applicable to 16 tape-controlled milling machines. Functions of a parts programmer, two IBM 705 computers, and of various operations and

checks are presented, with details of special equipment for the latter purpose built by the company.—S.H.-S.

**New approaches to machining** (*Aircraft Prod.*, 1960, **22**, Dec., 456–463) Machining at elevated temp., at ultra-high-speeds and with projectiles has been studied together with the effect of sub-zero coolants. Graphs are presented, tool life (or other comparable factor) being plotted against cutting speed. The appearance of the chips obtained by the different methods is shown.—C.V.

**Metal cutting** J. S. Campbell, S. Kobayashi, J. M. Galimberti, R. S. Hahn, and E. G. Thomsen (*Mech. Eng.*, 1960, **82**, Sept., 68–70) A review with 51 refs.—C.V.

**A photoelastic analysis of machining stresses** E. Usui and H. Takeyama (*Trans. ASME J. Eng. Indust.*, 1960, **82**, Nov., 303–308) Direct measurements of the distribution of normal and frictional stresses on a rake face under cutting conditions have been considered impossible but these can be obtained photoelastically by means of a tool made of photo-elastic material. The frictional stress on the rake face is uniform over a wide range of the tool–chip contact area reagrdless of the varying stress thereon; it decreases steeply near the point of chip separation. The normal stress on the rake face has its peak at the cutting edge; in the middle of the tool–chip contact length it tends to be stationary while in the outermost part it decreases almost linearly vanishing at the point of separation. Peak normal stress at the cutting edge corresponds to the singular force at the cutting edge (*ibid.*, 1958, **80**, 1096) and the distribution of normal stress in the shear plane is not uniform but increases towards the work surface. The experimentation is described.

**The role of friction in metal cutting** S. Kobayashi and E. G. Thomsen (*Trans. ASME J. Eng. Indust.*, 1960, **82**, Nov., 324–332) Controlled tool–chip contact-area studies with free-cutting steels show that friction processes on the tool face follow the composite rule of Holm, Bowden and Tabor, Ernst and Merchant, and Finnie and Shaw, *viz.*, that the normal load on the metal in the chip at the interface, divided by the bulk area of contact caused by seizure of asperities is equal to the mean bulk flow stress of the chip metal; also the friction stress is ~equal to the shear strength. Furthermore it was found that the artificial area of contact approached the bulk area. Controlled flank contact-area tests, like tool–chip contact areas appear to be suitable for friction studies when the shear angle is not affected by temp. rise in the workpiece surface; steel SAE 1112 was used. The single tool force inferred from intercept tool forces named tool-edge force, made the results obtained with alloy SAE 4135 in flank area studies less lucid. It is however considered that there is rubbing and therefore friction at the flank at small clearance angles and this appears to be confirmed by some of the experimental data.

**A critical comparison of metal-cutting theories with new experimental data** S. Kobayashi, R. P. Herzog, D. M. Eggleston, and E. G. Thomsen (*Trans. ASME J. Eng. Indust.*, 1960, **82**, Nov., 333–347) Orthogonal metal-cutting tests at varying cutting speeds rake angles, and feeds were carried out on steel SAE 1112 (annealed and as-received), steel SAE 1020 (as-received), steel SAE 4135 (annealed, as-received and Rockwell hardnesses 27 and 35–37), and Al alloys etc. With SAE 1112, both types, speeds of 0·083–1·010 fpm were employed and earlier findings were confirmed (*ibid.*, 1959, **81**, 251, and *Univ. Calif., IER Rep.* No.117); these showed that shearing stresses are independent of the stress conditions and the observations are supported by theoretical considerations. Correlations of metal-cutting data with compression data on the basis of the incremental or distortion energy theory hold for ductile metals but a less perfect agreement was found with SAE 4135 and Al-alloy 2024–T4. Furthermore it was found that none of the known theoretical angle relationships was in agreement with all the experimental data.—C.V.

**On the electro-erosion series of B.R. and N. I. Lazarenko from the point of view of the Lenz–Joule effect** I. A. Bakuto (*Trans. Akad. Nauk BSSR Minsk. Fizika-Technichny Institut. Sbornik Nauchnykh Trudov*, 1958, **5**, (4), 220–224; from *US Techn. Trans.*, 1960, **4**, Nov. 9, 505) An expression is derived which can serve for a qualitative comparison of the erosion effect at electrodes of different materials. Experimental data are tabulated for a series of metals obtained by B. R. and N. I. Lazarenko ('The physics of the spark machining of metals', in Russian, Moscow, 1946).

**Electroshaping. New approach to chipless machining** A. H. Milnes and C. A. Snavely (*Steel*, 1960, **147**, Nov. 7, 110–111) A new method of electroshaping, called Sifco Shaping, giving electrolytic machining with good removal rates, close control over the contours generated, and simple set up and operation, is explained.—S.H.-S.

**What electrochemical machining can do** D. Fishlock (*Metalw. Prod.*, 1960, **104**, Dec. 7, 94–98) Electromachining has four primary applications, superfinishing, deburring, grinding, and contouring. The advantages are, the ability to cut tough alloys and carbides at a constant rate, without thermal distortion, tool marks, burrs, or serious loss of fatigue strength. Metal removal is almost directly proportional to amperage. Electromachining rates are 75–90% of the theoretical value and it is stated that 1000 amp will remove ~0·1 $in^3$ of metal per min.—C.V.

**Forgings milled electrochemically** P. A. Oelgoetz and G. A. Clark (*Steel*, 1960, **147**, Nov. 7, 112) Electrochemical milling is briefly described and compared, in tabular fashion, with chemical milling, showing the similarities and differences of the two processes.—S.H.-S.

## CLEANING AND PICKLING

**Cleaning of components more quickly** Hockley Chem. Co. Ltd (*Engineering*, 1960, **190**, Dec. 16, 830–831) An account of a precision barrelling process and the Trowal-Vibrator (or Lacromatic Vibrator).

**Abrasive cleaning of shell and tube heat exchangers** R. F. Battistella, J. L. Powell, R. A. Yeakey, and S. Bernstein (*Ind. Eng. Chem.*, 1960, **52**, Dec., 46A–49A) Laboratory scale, pilot plant, and a full-scale mobile unit were constructed. Operation and performance are described.

**Acoustic irradiation used in descaling and cleaning wire** J. W. Howe (*Wire Wire Prod.*, 1960, **35**, June, 737; translated from *Draht-Welt*, 1959, March).

**The cleaning of carbon steel wire as affected by the metallurgical nature of the scale** A. B. Dove (*Reg. Tech. Meet. AISI, Preprint*, 1960, Sept., pp.29) Scale formation is reviewed and it is shown that cooling can be controlled so as to increase pickling rate and to reduce scale losses by 65%. Mechanical descaling and the effect of wire patenting on pickling are also included.

**New knowledge gained in the flame scarfing of rolled plate and sheet** H. Wiegand, F. Nieth, and W. Neuhaus (*Hüttenwerk Oberhausen, Tech. Ber.*, 1955–58, paper 32; reprint from *Metalloberfläche*, 1957, **11**, (4), 114–119) The various factors influencing the composition and thickness of the scale of rolled plate and sheet were studied and the removal of the scale by flame scarfing was investigated. It was found, *inter alia*, that the scale is removed easier the higher the $Fe_3O_4$ content of the scale is and the thicker the scale is, for instance at a thickness of more than 10 $\mu$ a removal rate of 90–100% was obtained.—T.G.

**Flame scarfing as a tool in the protection processes against corrosion in the chemical industry** W. Neuhaus (*Hüttenwerk Oberhausen Tech. Ber.*, 1955–58, paper 33; reprint from *Schweisstechnik*, 1958, **15**, pp.5) The advantages offered by the flame scarfing process in the preparation of steel surfaces for protection against corrosion in the chemical industry are stressed. Flame scarfing may also be used for drying the surfaces and for burning in or on passivation agents. The process is economic and in many respects superior to the conventional procedures.—T.G.

**Some applications of electropolishing** Haward Corp. (*Machinery*, 1960, **97**, Nov. 23, 1179–1181) Stainless steel and other parts are shown.

**Precision finishing parts by vibration** G. D. de V. Weston (*Metalw. Prod.*, 1961, **105**, Jan. 18, 67–68) The function is similar to that of the tumbling barrel, but in this unit the whole is vibrated at a high, variable speed; it is briefly described and examples of production work are given. With small mild steel pressings, deburring could be achieved in 40 min; with bulky parts, these must first be jig-mounted. A fully automatic unit is also available.—C.V.

**How to select steel abrasives** J. R. McConnell (*Steel*, 1960, **147**, Nov. 14, 114–115) Six guideposts, starting with microstructure, are presented for the selection of steel abrasives suitable for the type of job in hand.—S.H.-S.

**Blast descaling gains as free inspection tool** Wheelabrator Corp. (*Steel*, 1960, **147**, Nov. 14, 126) Mechanical blast descaling of slabs, billets, and bars before inspection is described and advantages experienced by several producers and users are enumerated.—S.H.-S.

**Mechanical descaling of steel wire rod in France** A. Liné and J. Peignier (*Wire Wire Prod.*, 1961, **36**, Feb., 181–190, 238) A detailed illustrated presentation of this problem. Wire drawing lubrication is well summarized. The grades of wire produced are listed, dry drawn bright wire, clean bright wire, welding, nail, and galvanized wires.—C.V.

**Properties and application of blasting materials for surface treatments, particularly by cut steel wire** W. Zieler (*Met. y Elect.*, 1960, **24**, Nov., 125–140; from *Draht Welt*) A review of various methods of surface cleaning by blasting and burnishing with metallic and non-metallic abrasives, applied by compressed air or liquid (water) with particular attention to scouring by cut wire and small cut steel particles as also by shot peening. A table of norms for the choice of size of grains and the mechanical resistance is presented, with data tabulated as to essential qualities of wire granules relative to their diameter, and the useful life of normal and nitrogen-hardened steel granules. In addition to cut wire the properties and performance of both angular and rounded grains of iron and cast steel are discussed.—S.H.-S.

**Effects of chemical composition on the pickling of surfaces of low-carbon steel strip** F. D. Ivanov (*Stal'*, 1961, (1), 57) A note from Novosibirsk. The formation of highly adherent scale on metal from Magnitogorsk is caused by reduced S and P and greater S segregation.

**Etching steel for adherence of porcelain enamel** F. W. Beall, R. L. Myers, and J. J. Canfield (*Amer. Ceram. Soc. Bull.*, 1960, **39**, Dec., 727–731) If etching of non-fish scaling, non-boiling steels followed by nickel flashing is carried out in the enamelling plant, good adherence will result and single coat practice can be followed. Two different groups of etchants are reviewed; one roughens the metal surface through differences in rate of attack on different crystal faces while the other forms pits in the metal surface. Twelve photomicrographs illustrate various aspects of this problem.—C.V.

**Investigations on a sulphate precipitation plant in a wire mill** W. Funke (*Neue Hütte*, 1960, **5**, Nov., 646–652) The experience gained in the neutralization and regeneration of sulphuric acid pickling wastes is reported with particular emphasis on the difficulties met with in regeneration. As the two types of disposal are used in the same works the comparison of the two under the prevailing conditions is very informative.—T.G.

**Recovery of acid and iron from ferrous sulphate bearing effluents** D. W. Becken (*Indust. Chem.*, 1960, **36**, Dec., 604–606) A review of published processes.

**Disposal of pickle liquor** W. Bullough (*Engineering*, 1960, **190**, Oct. 21, 554) Neutralization of unused acid with limestone is insufficient since $FeSO_4$ still causes pollution; with slaked lime this is removed as sludge but unused acid and alkali are wasted. Extraction as the heptahydrate is also considered together with methods and markets for the disposal of this. Methods based on the use of the monohydrate are discussed. With the Nordac method, acidity is <2·5% with a 79% fairly free-flowing $FeSO_4$ and the cost of plant operation is balanced by the value of acid recovered; with the Zahn method 7·8% $H_2SO_4$ and 72%

$FeSO_4$ are obtained. The conversion of the monohydrate to acid follows: The Chemical Construction Corporation mixed the monohydrate with 12%-wt of coal, sinter/fines, and pelletized the mixture; these pellets heated on a Dwight-Lloyd sintering machine gave sintered Fe-oxide and a gas containing 7·5%$SO_2$ which was scrubbed, filtered, dried, and converted to acid. In the autoxidation process the Nordac product was mixed with 2% by wt coal and indirectly heated in a rotating retort. The Fe-oxide is removed and the gas cooled and cleaned and absorbed in dilute $H_2SO_4$ plus a trace of $MnSO_4$, then flowing into an autoxiation tank where it is aerated; the $O_2$ reacts with the $SO_2$ to form more acid. Acid strengths ~30% w/w were obtained and the process is economical on a scale as low as 8 t/day. The Horner continuous electrolytic process is also discussed together with the HCl method.—C.V.

**Present state of regeneration of sulphuric acid pickling wastes** K. Mathesius (*Neue Hütte*, 1960, **5**, Nov., 641–646) The author describes and illustrates the various methods in use for neutralisation or regeneration of $H_2SO_4$ pickling solutions. The importance of this problem received a new impetus from the introduction of new legislation on water pollution in West Germany. The equipment and its operation are usually quite expensive, particularly if iron salts are to be obtained. For these reasons mechanical descaling will become of more importance.—T.G.

## PROTECTIVE COATINGS

**Specifications and controls of surface coatings** P. Orlowski (*Corros. et Anticorros.*, 1960, **8**, Nov., 421–427) A series of French and foreign standard specifications is presented in tabulated form, with indications of their character and instructions for their use.

**The Nernst equation and its use in electroplating technology** K. Müller (*Metalloberflache*, 1960, **14**, Sept., 261–266) The Nernst equation was derived from thermodynamic considerations, and some practical examples of its application in the field of electroplating are discussed.

**The electroplating of low alloy steels** O. Niedermeyer (*Metalloberflache*, 1960, **14**, Sept., 285) Notes on the electroplating of cylindrical parts made from VCMO bar steel (0·22–0·29%C, 0·15–0·35%Si, 0·50–0·80%Mn, 0·90–1·2%Cr, 0·13–0·25%Mo) are given.

**Surface treatment of structural parts made of cold-rolled strip** E. F. Göbel (*Bänder-Bleche Rohre*, 1960, Sept., 23–27) Structural parts made of cold-strip steel are often protected against rusting or they receive a coating for decorative purposes. The author describes common practice of electroplating, phosphating, and lacquering of parts made of strip steel.

**A precision instrument for testing the thickness of electroplates by electrolytic stripping method** P. B. Mathur (*Plating*, 1960, **47**, Nov., 1274–1276) The instrument and its use are described.

**Eddy currents measure coating thicknesses** P. Dick (*Steel*, 1960, **147**, Dec. 12, 84) An eddy current tester probe working on flat or curved surfaces is described.—S.H.-S.

**Precoated metals solve manufacturers' problems** J. Jenner (*Prod. Fin.*, 1960, **13**, Nov., 84–92) The wide range of precoated metals now available is reviewed and discussed and their many and varied applications are presented and compared.—S.H.-S.

**Developments in chrome electroplating as a protection against corrosion** P. Morisset (*Corros. et Anticorros.*, 1960, **8**, Nov., 407–418) The characteristics of hard Cr plate deposited directly on the metal base, and those of decorative chromizing, applied on an under-layer of Ni or Ni+Cu and much more thinly, are described, and various tests, showing the influence of different parameters in the protection against corrosion by the electrolytic deposit of Cr, comparing both classic methods and present-day techniques, are discussed.

**A study of the minimization of the adverse effects of chrome plating on the fatigue life of AISI 4340 steel and the correlation of fatigue and elastic limits** J. Viglione (*ONR–5*, **2**, *PB* 141471, 509–522) Efforts to increase strength to ~300000 psi by heat-treatment introduced embrittlement problems on a Cr plating. Shot peening reduces the tendency and so does baking. This is now included in specification QQ–C-320. Tests to find the level at which this became necessary are described.

**Electrodeposition of chromium alloys and study of elevated-temperature properties of certain electro-deposited metals and alloys** P. T. Woodbury and W. G. Hespenheide (*PB* 148736, 1955, Feb., pp.28; from *US Res. Rep.*, 1960, **34**, Nov. 18, 621) One of the objectives of the work in this report period was to continue the elevated-temp. oxidation studies of electrodeposited metals in liquid- and vapour-phase $MoO_2$. Another objective was to determine the effect of changing the composition of Cr–Fe alloy on its coefficient of thermal expansion and permanent change in length after heat-treatment. Another objective was to determine the expansion and contraction behaviour of electrodeposited Co–W alloy and of a specimen of stress-free nickel (13 refs).—C.F.C.

**Electrodeposition of chromium alloys and study of elevated-temperature properties of certain electrodeposited metals and alloys** G. R. Shaer and P. T. Woodberry (*PB* 148737, 1955, June, pp.21; from *US Res. Rep.*, 1960, **34**, Nov. 18, 621) One of the objectives of the work during this period was to determine whether alternate layers of Ni and Cr plate could be diffused at 100 or 1150°C to form a Ni–Cr alloy. A second objective was to confirm the superiority of stress-free nickel plate over stressed nickel plate as regards denseness after heat-treatment. A third objective was to compare the hot hardness of Cr with Cr–Fe alloy plates.—C.F.C.

**Electrodeposition of chromium alloys and study of elevated-temperature properties of certain electrodeposited metals and alloys** G. R. Schaer and J. A. Gurklis (*PB* 148738, 1955, Aug., pp.38; from *US Res. Rep.*, 1960, **34**, Nov. 18, 621–622) Diffusion of Ni–Cr plating and its oxidation in air and in fused $MoO_2$ were studied, and its adhesion to steel.—C.F.C.

**Use of selenic acid for plating microcracked, protective and decorative chromium plate** W. H. Safranek and R. W. Hardy (*Plating*, 1960, **47**, Sept., 1027–1031) The addition of selenic acid to the plating bath induces microcracking in the Cr plate. This gave improved corrosion performance with decorative composites of Ni and Cr. With 0·8 mil of bright-Ni and 0·055 mil of microcracked Cr on a set of Zn die cast panels no corrosion was found after 144 h of Cu-accelerated salt spray. Depositing is 5 min plating time and the effect of altering the selenic acid concentration in relation to cathode current density is discussed. Further work relating to changes in appearance on outdoor exposure is being undertaken (14 refs).—C.V.

**The effect of surface preparation on the tensile strength, hardness and adhesion of electrodeposited nickel** P. A. Brook (*Plating*, 1960, **47**, Nov., 1269–1273) A new method of measuring tensile strength was developed and this and hardness are shown to be independent of surface preparation. Adhesion is, however, greatly affected, mechanically scoured surfaces being least and electropolished surfaces most suitable.

**The application of a new bright-nickel plating method** H. H. Reinsch (*Metall-Rein.*, 1960, **9**, Nov., 193–194) The advantages of duplex nickel plating for the increase in corrosion-resistance of the underlying steel are described. The second layer closes the pores left by the first, the second plating operation also exercises a levelling effect, which is most welcome in motor car trimming production.

**Testing the thickness of nickel-chromium plating** (*Inco-Mond Mag.*, 1960, (16), 27–29) Sectioning, the B.N.F. jet test, the coulometric method, the B.N.F. thermo-electric gauge, and the Magne-gauge tests are summarized and briefly described.—C.V.

**Electrodeposition of nickel-cobalt alloys from the pyrophosphate bath** V. Sree and T. L. Rama Char (*J. Electrochem.*, 1961, **108**, Jan., 64–70) Detailed studies on alloy composition, cathode efficiency, and potential show the optimum conditions. These are described in some detail.—C.V.

**Nickel–aluminium alloy coatings resist corrosion at 1000°C** D. E. Couch and J. E. Connor (*Iron Age*, 1960, **186**, Oct. 20, 156–157) A method for providing Ni–Al alloys with optimum corrosion resistance, while reducing overall forming problems has been devised by the National Bureau of Standards in conjunction with Wright Air Development Centre in a two-stage process, which first electroplates nickel over the desired base metal (steel, Ni, or Mo) and then plates Al over the nickel at 700°C. Results are reported.—S.H.-S.

**Electrodeposition of cobalt–molybdenum alloys** A. Krohn and T. M. Brown (*J. Electrochem. Soc.*, 1961, **108**, Jan., 60–64) The deposition of Fe–Mo alloys from pyrophosphate solutions is briefly reviewed and a similar bath is employed for Co–Mo alloys, $N_2H_4$, $HSO_4$ being added to the plating bath to prevent anodic oxidation of $Co^2$ to $Co^3$; this also increases cathodic current efficiency and increase in Mo in the deposits; further improvement results from wiping the cathode during plating. The average content of the deposit was Mo 56, Co 37, and 7% nonmetallic material and the deposits were bright and adherent although they tarnished rapidly unless a protective coating was applied.—C.V.

**New low-carbon steel fills gap in porcelain-enamel industry** Bethlehem Steel Co. (*Iron Age*, 1960, **186**, Oct. 20, 151–153) A one-coat porcelain-enamelling steel, which eliminates the need for the ground coat, is reported as reducing overall enamelling costs by 15–30%. Various pretreatments are listed, with results.

**The unexploited field** (*Product Fin.*, 1960, **13**, Dec., 93–95) The use of vitreous enamel for large decorative schemes is advocated.

**Practical establishment of rectangular wire enamelling speeds** R. E. Zauner (*Wire and Wire Prod.*, 1960, **35**, March, 460–462, 505–507) A convenient method of constructing curves to predict the wire speed for enamelling rectangular wire is explained. By making three trial runs with suitable wires, and inserting the results in the given equations, values are obtained from which wire-size/wire-speed relations can be deduced.

**Paints and resins for steel tanks** J. O. Jackson (*J. Amer. Water Works Assoc.*, 1960, **52**, Nov., 1379–1385) A general review of red lead paints and of the various types of synthetic resin, nitrocellulose, and chlorinated rubber coatings.

**Protective painting of coke oven plant** R. Nichols (*Year Book, Coke Oven Man. Assoc.*, 1960, 252–262) Various primers, undercoats, and finishing coats are examined, the time to complete failure or condition after 570 days being recorded. The final performance of each of the undercoatings seems to depend on the finishing coat. For instance, after 570 days, red lead/red lead/micaceous ore system gave the same results as red lead/Ca-plumbate/$TiO_2$, but Ca-plumbate was a failure when used as an undercoat for white lead/graphite paint. In general the Pb-based undercoats appeared successful in mitigating the blistering which is common with paint films in water-sealed holders. Synthetic and natural oil paints were variable being reasonably successful if applied over the 'correct' undercoat and primer; a Cl-rubber paint gave reasonable success but a coal tar emulsion was unsatisfactory. Anodic metals/synthetic resin system (probably a rich Zn-paint) has so far given good performance.

**Why paint castings?** R. H. Herrmann (*Foundry*, 1960, **88**, April, 79–81) The spraying with a primer, and painting of large, medium, and small castings, in order to prevent rusting and contamination and to show up surface irregularities and so assist their correction, is briefly described.—S.H.-S.

**Overhead conveyor eliminates painting bottleneck** R. R. Hill (*Products Fin.*, 1960, **25**, Nov., 52–55) A lightweight system is described that leads in and out of new painting and baking areas; farm implements are dealt with and the operations are carried out in 1600 $ft^2$. Apart from space saving, the system enables a better job to be done in one shift that was done by two with the old method. 16in radius curves are used so that the conveyor makes four passes through the drying oven; other details are provided.—C.V.

## CLAD SHEET AND HARD-FACING

**Stainless steel foil sticks tight** Avery Adhesive Products Inc. (*Steel*, 1960, **147,** Dec. 26, 68–69) A pressure sensitive foil (0·003in thick) has been developed to cover almost any clean, smooth surface with stainless steel at low cost. Maximum foil width is 16in and various applications, covering for protection against corrosion, are suggested.—S.H.-S.

**For a stronger metal surface** A. J. Schwarzkoff (*Product Eng.*, 1960, **31,** Nov. 14, 70–74) Hardening and 'overlaying' are compared with special reference to the service requirements. A brief summary of carburizing, nitriding, and carbonitriding is given and spray coating and hardfacing are briefly outlined.—C.V.

**Hard chromium plating of cylinder liners** Laystall Eng. Ltd (*Met. Fin. J.*, 1960, **6,** Oct., 404–405; *Engineering*, 1960, **190,** Nov. 18, 698) The plating process carried out by Canning automatic units for the mass production of Laystall 'Cromard' steel cylinder liners for internal combustion engines is briefly described.—S.H.-S.

**Canning automatic hard-chromium plating installation** Canning & Co. Ltd (*Machinery*, 1960, **97,** Nov. 23, 1195–1196) An installation supplied to Laystall-Chromard Ltd for cylinder liner plating is described.

**Chromallize for heat and wear resistance** Chromalloy Corp. (*Metalw. Prod.*, 1960, **104,** Dec. 21, 64–66) Cr diffusion is being used to protect superalloy turbine blades from the ravages of heat, corrosion, and erosion, and cobalt alloy blades treated by chromallizing have withstood 2200°F. Among many hard-facing and corrosion-resisting applications for the powder diffusion technique, parts to be treated are packed in a retort containing a powdered compound of Cr and for other metals, a catalyst, and inert matter to permit gas circulation. Comparative data are presented.—S.H.-S.

**Diffusion coatings protect metals to 2300°F** Haynes Stellite Co. (*Mat. Design Eng.*, 1960, **52,** Dec., 17) Ni and Co-base alloys, stainless and plain C-steels have been coated. No details are given as to the nature of the coatings but they are metallurgically bonded to the base metal and resist spalling, chipping, and thermal shock and can be applied to wrought or cast metals; thickness ranges from 0·001 to 0·006in and internal holes and recesses can be coated. The coatings are applied at an unspecified high temp. and possible metallurgical changes must be considered; also, at the present stage, only parts 15in × 16in × 18in can be treated, although when equipment becomes available there would appear to be no reason for this limitation. Oxidation wt changes at 200° (500 h) and 2300°F (100 h) and tensile properties at 80–1800°F for coated and uncoated specimens are given.—C.V.

**New techniques for cladding with the gas shielded process** R. D. Engel (*Weld. J.*, 1960, **33,** Dec., 1222–1229) An improved fusion cladding process was developed by combining the extended-electrode gas-shielded process with a curvilinear oscillating device. The resulting overlay process produces high-quality overlays at high-deposition rates when used with dc reverse polarity. The process can be used to deposit stainless steel, nickel, and copper-base alloys, and various other weldable materials. Long electrode extensions produce deposition rates 50 to 100% higher than can be obtained with normal extensions of $\frac{1}{2}$ to $\frac{3}{4}$in, and have also resulted in substantial reduction in weld metal dilution.—S.H.-S.

**Multimetal parts from clad metal strip** B. Coad (*Prod. Eng.*, 1961, **32,** Jan. 9, 69–71) Three main reasons are given for using clad metals in precision electrochemical devices. Valuable metal is conserved, being only used at the surface or in an isolated area of a part, the properties of the components can be combined or new properties, unobtainable with a single metal or alloy, can be achieved. A series of parts and shapes, strip, rod, and wire tubing, etc., is shown and the method of attaining this cladding is briefly discussed. Examples of base metal (Cu, Ni, Mo, etc.) cladding (Ag, Sn, Al, glass sealing alloy, etc.), the suggested forms and the applications are also given.—C.V.

**Thermal non-similitude and tensile strength using the Camlachie cramp** T. Takahashi and I. Hagiwara (*Imono*, 1960, **32,** March, 178–185) Welding of cast iron to steel is examined in terms of volume ratio. In the Camlachie cramp there are volume changes which interfere with the relation between volume ratio and welding quality. Mo steel shows increased tensile strength.

**The graphical method of study of the solidification process in the Camlachie cramp** I. Hagiwara and T. Takahashi (*Imono*, 1960, **32,** April, 233–240) The remelt phenomenon was difficult to detect in the steel core surrounded by molten cast iron, but graphical plotting of the temp. changes gave some information. The volume ratio must be combined with the ratio of volume to surface area to calculate the degree of melting.

**Flame spraying of aluminium oxide** D. G. Moore (*Met. Fin. J.*, 1960, **6,** Oct., 397–403) The particle-impact process in the spraying of $Al_2O_3$ is studied and results are briefly reviewed.—S.H.-S.

## POWDER METALLURGY

**On the production of iron powder in Czechoslovakia** M. Petrdlik (*Hutn. Listy*, 1960, **15,** (11), 857–860) The technology of production of high quality iron powder is surveyed, and recommendations concerning specific processes best suited in powder metallurgy and electrode manufacture in Czechoslovakia are made.

**Report of Committee B-9 on metal powders and metal powder products** (*Proc. ASTM*, 1959, **59,** 330–332) A method for hardness testing of sintered metal friction materials, and various specifications, are recommended for publication as tentative. The activities of the committee are reported.

**Surface treatment of products of iron powder metallurgy** P. Széki (*Metalloberfläche*, 1960, **14,** Sept., 266–269) Subjects discussed are: the influence of pickling medium and electrolytic baths on the sintered metal; corrosion protection of sintered parts; production of iron oxide in the vapour phase on iron sintered parts; deposition and testing of electrolytic coatings.

**Stress infiltration of two phase alloys** G. Matsumura (*Planseeber*, 1960, **8,** Dec., 110–118) [In English] Letting the infiltrated metal solidify from all sides introduces a tension or compression. Iron was infiltrated with Cu and Bi. The former expands and the latter shrinks. Tension decreases and compression improves tensile strength.

## FERRITES, CERMETS, AND CARBIDES

**Iron–alumina materials** A. Gatti (*57–RL–1748, May*, pp.14; from *Nucl. Sci. Abs.*, 1960, **14,** Nov. 30, 3014) Mixtures with 8–10%$Al_2O_3$ were made by oxidation-reduction of Fe–Al alloys, by coprecipitation of hydroxides, by mixing of colloidal oxides and by mixing colloidal Fe powder with $Al_2O_3$. These were reduced in $H_2$, compacted and extruded at 2200°F. Structures, tensile, and creep properties were determined; these are much higher than with pure iron.

**Electrical resistivity of nickel ferrite** H. Lord and R. Parker (*Nature*, 1960, **188,** Dec. 10, 929–930) A letter. Evidence for oxygen loss during sintering was found.

**Study of iron carbides obtained by chemical synthesis in the pure state and by substitution** M. Osdoit (*Bull. Cercle Etudes Mét.*, 1960, **8,** Sept., 113–129) A study of carbides and particularly of cementite, relative to the action of Ni, Co, S, N, B, Si, Mo, and Mn upon these, and upon the properties of pure carbides and some metalloid replacements, is presented.—S.H.-S.

**Crystallographic data: niobium monocarbide** E. R. Storms, N. H. Krikorian, and C. P. Kempter (*Anal. Chem.*, 1960, **32,** Nov., 1722) X-Ray powder data are given.

**Crystallographic data: Dimolybdenum carbide** R. J. Fries and C. P. Kempter (*Anal. Chem.*, 1960, **32,** Dec., 1898).

## PROPERTIES AND TESTS

**Comparison of materials** (*Mat. Design Eng., Materials Selector Issue*, 1960, **52,** mid-Nov., 11–35) Lists of the physical and mechanical properties of metals and non-metals are given including, density, thermal properties, electrical properties, elasticity, yield strength, hardness, impact properties, creep strength, and effects of irradiation.

**Irons and steels** (*Mat. Design Eng., Materials Selector Issue*, 1960, **52,** mid-Nov., 37–81) Surveys of the properties of irons and steels are given including grey, nodular, and malleable irons, carbon, low-alloy, and stainless steels, and superalloy, heat-resistant, and tool steels, including compositions.

**Report of Committee A-10 on iron–chromium, iron–chromium–nickel and related alloys** (*Proc. ASTM*, 1959, **59,** 158–162) Alterations, additions to, and deletions from standard and tentative specifications are given.

**The production of iron single crystals by zone melting** H. Hillmann and A. Mager (*Z. Metallk.*, 1960, **51,** Nov., 663–666) The apparatus and procedure for producing single crystals of high-purity iron by zone melting is described. The results indicate that the orientation of the α-single crystal is determined by the initial formation of a δ-single crystal.

**Arc zone-refining** J. Zbořil (*Hutn. Listy*, 1960, **15,** (11), 861–864) Steel contained in a boat travelling through a hot zone, generated by the electric arc of a W electrode in an argon-filled tubular vessel, was zone refined. W was not found to be present on examining the refined product spectroscopically. The method is recommended for zone refining reactive metals of high melting-point.—P.F.

**Basic elements of quality of steel ropes** E. Provci (*Zastita Mat.*, 1960, **8,** Nov., 468–478) Types and characteristics of steel wire and its influence on the quality and life of steel ropes; types and characteristics of stuffing for steel ropes, and its effect to the quality and life of steel ropes; ways of greasing the stuffing, steel bunches, and steel ropes and the relative effect on the quality and life of steel ropes were examined.—C.F.C.

**Types and proper choice of steel ropes** R. Kristovic (*Zastita Mat.*, 1960, **8,** Nov., 479–491) The problem of ordering the proper types, and general ideas of construction and makes of steel ropes; proper handling of steel ropes, and their mounting, particular characteristics of abraded steel ropes depending on type of rope; and choice of steel ropes in respect of particular uses in various branches of industry were examined.—C.F.C.

**Standardizing steel ropes** B. Stankovic (*Zastita Mat.*, 1960, **8,** Nov., 500–504) Aim of standards; nationalization of types; fixing production tolerances, quality, uniform methods of testing, safety regulations; leads for production process and for use as well and fixing uniform marking and uniform delivery terms are considered. Standards making up specifications for ropes; types of standards and other regulations related to ropes; the position of standards in some countries; German, British, French, Czechoslovakian, Soviet, Italian, and Yugoslav standards and the problem of an international standardization are discussed.—C.F.C.

**Quality testing conditions and control of accuracy of steel ropes** M. Dulic (*Zastita Mat.*, 1960, **8,** Nov., 519–524) Showing methods and means for testing steel wires as the elements of which ropes are made, as well as for testing the ropes themselves. In testing procedure for steel wires and ropes a dimensional checking in first of all performed in regard to the tolerances prescribed, and in consequence checking of all mechanical characteristics concerning stretching strength, resistance to bending, and torsion as well as testing of the quality of tin coatings are gone into. In certain cases various dynamical tests should apply in order to determine the characteristics of the material in regard to tenacity and resistance to abrasive effects.

**On the overheating of iron** A. Kohn (*Compt. Rend.*, 1961, **252,** Jan. 30, 725–727) A study by thermal analysis has evidenced the importance of superheating before solidification (more than 150°C) that can be observed in samples of pure iron, of Armco iron, and of recast basic Bessemer steel. The extreme dispersion of the values observed cannot be explained by present theories on nucleation.—S.H.-S.

**On the mechanism of yielding and flow in iron** H. Conrad (*JISI*, 1961, **198,** Aug., 364–375) [This issue].

**Mechanical properties of low-alloy steels (rolled sheets)** G. V. Uzhik, M. Ya. Gal'perin, P. F. Koshelev, G. L. Livshits, and Ya. K. Terent'eva (*Stal'*, 1961, (1), 68–73) Properties of these steels were examined and a preliminary report is presented. The low-temp. properties, showing no tendency to embrittlement were included. The work is part of the programme to use lighter sections of the cheaper low-alloy steels instead of the conventional carbon steel structural units.

**Symposium on particle size measurement** (*ASTM. STP*, No.234, 1959, Aug., pp.303). **The mechanics of fine sieving** K. T. Whitby (3–25). **Application of electroformed precision micromesh sieves to the determination of particle size distribution** H. W. Daeschner, E. E. Seibert, and E. D. Peters (26–50). **Methods of particle size analysis** R. P. Loveland (57–88) (41 refs). **Sedimentation procedures for determining particle size distribution** W. F. Sullivan and A. E. Jacobsen (98–116). **Centrifuge sedimentation size analysis of samples of airborne dusts collected in membrane filters** K. T. Whitby, A. B. Algren, and J. C. Annis (117–126). **Light scattering instrumentation for particle size distribution measurements** C. T. O'Konski, M. D. Bitron, and W. I. Higuchi (180–205). **Turbidimetric particle size distribution theory: application to refractory metal and oxide powders** A. I. Michaels (207–244). **The determination of particle size by adsorption methods** R. J. Fries (259–278). **A study of the Blaine fineness tester and a determination of surface area from air permeability data** S. S. Ober and K. J. Frederick (279–285).

**Polarization capacitance determinations of surface roughness** M. K. Testerman (*WADD Techn. Rept.* 60–97; *PB* 161847; from *US Res. Rep.*, 1960, **34,** Oct. 14, 479) Studies in KCl solution and in non-aqueous KCl systems (methanol, glycerol, formamide). Stainless steel and non-ferrous metals were used.

**Nickel-free high temperature alloy resists sulphur and sulphur-bearing atmospheres** D. J. Schmatz (*Mat. Design. Eng.*, 1960, **52,** Dec., 18) Austenitic Fe-base alloys containing no Cr or Ni are discussed (9%Al, 30%Mn, 1%Si, 1%C) these possessing excellent resistance to oxidation and strength from room temp. to 1400°F. Ductility is adequate for forming, although the higher yield-strength requires higher working forces during forming. With cold working and ageing, optimum strengths are obtained. Commercial stainless steels are somewhat superior to oxidation at elevated temp. but the new alloys are more resistant to S.—C. V.

**Steels containing more than 1% of boron** Z. Eminger (*Hutn. Listy*, 1960, **15,** (12), 955–961) B steels are often desirable for protection against high energy particles. The production and properties of three high-boron steels, developed in Czechoslovakia, are described in detail. A good eutectic boron steel should, it is suggested, contain 0·15%C max., 0·50%Mn max., 1·5%Si max., 0·5%Al max., and 3–3·5%B.—P. F.

**New tool steel gives long life** D. W. Kaufmann (*Iron Age*, 1960, **186,** Dec. 15, 108–109) A new tool steel, Rex 49, is reported, which is claimed to out-perform other high-speed steels, increasing tool life two to four times, with increases in speed, feed, and depth of cut. Comparative tables of performance on highly-alloyed steels, stainless steels, superalloys, and Ti are presented.—S. H.-S.

**AISI Type 304L stainless steel with improved strength** R. R. Brady (*Trans. ASTM*, 1959, **59,** 774–785) The effect of nitrogen additions to type 304L steel (19/9 with 0·03%C max.) has been investigated, and the physical and corrosion resistant properties compared with those of normal type 304L steel, and of type 304 steel (19/9 with 0·08%C max.).

**Relationships between composition and properties of austenitic chromium–manganese–carbon–nitrogen stainless steels** A. Kasak, C. M. Hsiao, and E. J. Dulis (*Proc. ASTM*, 1959, **59,** 786–801) The results of this investigation show that the properties of austenitic Cr–Mn–C–N steels depend primarily on the amounts of carbon and nitrogen in solution in the austenite. By means of the data given here, a fairly accurate picture of the final properties of such a steel can be formed.

**Property relationships of some cast and forged Cr–Mn–Ni–N steels containing 18 per cent chromium** K. Haefner, A. F. Lahr, W. L. Meinhart, and J. J. Kanter (*Proc. ASTM*, 1959, **59,** 804–815) The properties of steels of composition 18%Cr, ~0·08%C, and 0–18% Mn, 0·8%Ni, 0–0·5%N were determined. Corrosion resistance, strength, ductility, and embrittlement at elevated temp. were considered.

**Development of a ductile, oxidation-resistant and high strength single-phase (austenitic) alloy based on Fe–Al–Mn–C system** R. C. Gibson (*PB* 148003; from *US Res. Rep.*, 1960, **34,** Oct. 14, 480) Work was initiated to develop a ductile oxidation-resistant and high-strength alloy based on the Fe–Al–Mn–C system for use at intermediate temp. (1100–1400°F). Results of heat treating studies performed on an Fe–Al Mn–C–Mo–W–V base alloy containing additions of copper and nickel have revealed that copper has little or no effect on the hardness of the alloys when aged in the temp. range 1100–1400°F. Nickel, however, was observed significantly to increase the hardness of the alloys during ageing at these same temp. Based on hardness data, there is no apparent interaction between copper and nickel which affects the ageing characteristics of the alloy.

**Development of a ductile, oxidation-resistant and high strength single-phase (austenitic) alloy based on Fe–Al–Mn–C system** R. C. Gibson (*PB* 148785, 1960, Feb., March, pp.11; from *US Res. Rep.*, 1960, **34,** Nov. 18, 625) Studies performed on an Fe–Al–C–Mo–W–V base alloy containing additions of Ni, and Cu indicated that Cu lowered stress-rupture properties and improved oxidation resistance. Ni additions increased stress rupture and room-temp. tensile properties of the base alloy, but had little effect on oxidation resistance.

**Ni-SPAN-C, an alloy having constant elasticity modulus** O. B. Jong (*Metalen*, 1961, **16,** Jan. 16, 2–6) This material is a heat-resistant Ni–Fe–Cr–Ti alloy capable of being tempered and having a constant elasticity modulus over a range from −50 to +66°C. Its mechanical properties are similar to those of VC Mo 240 alloy steel. Its physical and mechanical properties, applications, and methods and working are also dealt with in the article.—F. B. H.

## METALLOGRAPHY

**Metallography. On the modifications of structure observed by electron microscopy in the course of annealing cold-worked iron** C. Messager and P. Morgand (*Compt. Rend.*, 1960, **251,** Dec. 5, 2701–2703) A study of specimens of Armco iron showing the structure after cold-working.—S. H.-S.

**Microscopical test coupons—report of the Ductile Iron Research Committee, 12K** H. W. Ruf, D. Matter, A. W. Anderson, D. M. Marsh, A. H. Rauch, W. M. Spear, D. L. Crews, and H. G. Haines (*Mod. Castings*, 1960, **38,** Nov., 117–118) A study was made of methods for determining ductile iron graphite structure. On the basis of the study, it was concluded that microscopical examination of a separately cast test coupon was the most economical and rapidly applied single test. A test coupon was designed and found to be satisfactory.

**Direct observation of lattice defects in cold-worked high manganese steels by means of electron microscopy** Z. Nishiyama and K. Simizu (*J. Phys. Soc. Jap.*, 1960, **15,** Nov., 1963–1969) [In English].

**Note on the interaction of interstitially dissolved carbon atoms in α-iron** A. J. Bosman, P. E. Brommer, L. C. H. Eykelenboom, C. J. Schinkel, and G. W. Rathenau (*Acta Met.*, 1960, **8,** Oct., 728–729) A letter. It is concluded that $\Delta_{Pr}(t)$ is mainly due to a redistribution of pairs of carbon atoms, even though the diffusion mechanisms leading to this redistribution are not exactly known. From the binding energies for the carbon pairs, it may be estimated that about 15% of the carbon atoms are bound in pairs.—S. H.-S.

**French research in metallurgy achieved by means of the radioactive elements** A. Kohn (*French Science News*, 1960, No.3, July–Sept., 5–10; from *Acta Electronica*, 1960, **3,** (3–4), 253) [In English] A short review of research is presented and discussed, covering conditions of use of radioactive elements in metallurgy, with a study of segregations, observations in the phenomena of grain joints, the measurement of diffusion coefficients, radioactive techniques applied to three forms of chemical analysis, with a brief study of various physical or physico-chemical processes, and an examination of industrial processes.

**Behaviour of the change of carbides due to heat-treatment in the high-W high-Cp high-speed steel. (Study on the carbides in high-speed steels by electrolytic isolation. III)** S. Koshiba, S. Kimura, and H. Harada (*Tetsu-to-Hagane*, 1960, **46,** Oct., 1446–1450) The composition, crystal structure, and particle size of carbides were studied after electrolytic isolation. Changes produced by heat-treatment from the quenched state were followed.

**Effects of tempering time and repeated tempering on carbides in high-speed steels. (Study on the carbides in high speed-steels by electrolytic isolation. IV)** S. Koshiba, S. Kimura, and H. Harada (*Tetsu-to-Hagane*, 1960, **46,** Nov., 1554–1558) Effects at 575°C in low-W steels were examined. More are formed in 1 h at 650° than in 100 h at 575°C. $M_6C$ and MC types appear in short-time tempering and $M_{23}C_6$ types only after 50 h.

**Carbides in molybdenum steels** T. O. Sato, T. Nishizawa, and K. Tamaki (*Nippon Kinzoku*, 1960, **24,** (6), 395–399) Carbides formed by tempering are different from those from isothermal transformation but tend to approximate during prolonged treatment at 700°C. Five types appeared as the Mo:C ratio increased of which $M_6C$ and $M_{23}C_6$ are ferromagnetic. Composition ranges are given.

**On titanium carbide. (Study of non-metallic inclusions in iron and steel with an electron microscope. I)** K. Narita and K. Mori (*Tetsu-to-Hagane*, 1960, **46,** Oct., 1442–1446) Particle size was related to heat-treatment, also the change of lattice constants. The composition also appears to change with temp. of heat-treatment. Grain size is related to quantity of precipitated carbide which appears to be the controlling factor in the Fe–Ti–C system.

**The martensite transformation in carbon steels** P. M. Kelly and J. Nutting (*Proc. Roy. Soc.*, 1960, **259A,** Nov. 22, 45–58) Martensite formed in plain carbon steels containing less than 1·4% has been studied by direct-examination of thin foils in the electron microscope. It was found that the martensite in low-carbon steels forms predominantly as long needles parallel to $<111>M$, while in the high-carbon steels it forms as plates internally twinned on a fine scale. The existence of these narrow twins in the high-carbon martensites enables the transformation mechanism to be derived uniquely. This mechanism, which is largely in agreement with those previously proposed, explains all the observed experimental data. The observed change in the morphology of the martensite from needles to plates as the carbon content increases suggests an explanation of the change in hardness of quenched steels with change in the percentage carbon.—S. H.-S.

**Effect of prior heat-treatments on the rate of sigma transformation** K. Kunada (*Nippon Kinzoku*, 1960, **24,** (6), 335–339) Steels with 35–60%Cr annealed 500 h at 500°, cooled in the furnace from 1000°, or quenched from 900° and annealed at 650, 700°, or 750° for up to 300 h were used. Sigma formation was greatest for the 500° treatment, possibly owing to nucleation during treatment.

**Effect of metallic calcium on the stability of cementite in Fe–C–Si alloy** M. Maruyama and M. Ito (*Imono*, 1960, **32,** March, 167–171) By using a metallic Ca addition rather than the normal Ca–Si the effect of Ca was separated from any deoxidizing process. In irons of nearly the same oxygen content, Ca addition had a very strong anticementite forming action.

**On the relationship between structure and oxygen in Fe–C–Si alloys** M. Kikuchi (*Imono*, 1960, **32,** March, 172–177) Vacuum-melted specimens were studied and the structures observed are attributed to the $O_2$ contained in the melt, and graphite formation and inhibition effects by various kinds of oxide inclusions are identified.

## CORROSION

**Corrosion of metals** H. D. Mallon (*Eng. Mat. Des.*, 1960, **3**, Dec., 742–747) A summarized review with much illustrative data (13 refs.).

**The corrosion of iron and steel** K. A. Chandler (*Year Book, Coke Oven Man. Assoc.*, 1960, 396–411) Despite the fact that steelwork in the proximity of coke ovens is exposed to severely corrosive conditions, the effects can be greatly lessened by the use of protective coatings, low-alloy steels, stainless steels, and even cathodic protection. Rusting in air, water, and soil, the various preventive measures in relation to special locations are briefly examined.—C.V.

**Report of Committee A-5 on corrosion of iron and steel** (*Proc. ASTM*, 1959, **59**, 127–132) The various standard and tentative standard revisions recommended are given. These refer mainly to galvanized products.

**Report of Advisory Committee on corrosion** (*Proc. ASTM*, 1959, **59**, 333–338) Changes of personnel and the activities of all committees whose work involves corrosion testing are given (20 refs).

**The chemistry of materials failure** A. H. Bushey (*Mat. Design Eng.*, 1960, **52**, Dec., 99–103) The conditions under which a material will react, the speed of the reaction and the basic chemistry of corrosion are briefly discussed and the possibility of catalysis speeding up these reactions is suggested. These various changes, together with temp., stresses, and strains are regarded in terms of mechanical failure.—C.V.

**Translation of terms relating to metallic corrosion** U. R. Evans, Centre Belge d'Etude de la Corrosion, W. Meister, and R. B. Mears (*Acciaio Innossid*, 1960, **27**, Nov.–Dec., 550–555) Equivalents in German, Italian, English, French, and Russian are given.

**Resistance of materials** G. P. Gladis (*Chem. Eng. Prog.*, 1960, **56**, Oct., 46–49) A survey outlining the performance of common metals and alloys found in systems handling wet chlorohydrocarbons, $Cl_2$, $NH_3$, and $SO_2$. Five tables of corrosion tests are presented.

**Steel corrosion mechanisms under conditions pertinent to steam power generation** M. C. Bloom and M. B. Strauss (*AD 232430; NRL–5427*, 1959, Dec., pp.54; from *Nuclear Sci. Abs.*, 1960, **14**, Nov. 15, 2836) X-ray studies of pitting in sealed capsules, effects in commercial piping and effects of water treatment agents were investigated. The presence of a protective coating with a spinel structure was revealed and the formation and behaviour of $\gamma$-FeOOH are considered.—C.F.C.

**Corrosion fatigue of steel** K. Iwamoto (*Tetsu-to-Hagane*, 1960, **46**, Nov., 1564–1571) [In Japanese] A review.

**Corrosion of prestressed wire in concrete** G. E. Monfore and G. J. Verbeck (*J. American Concrete Institute*, 1960, **32**, Nov., 491–515; from *Brit. Rail. Monthly Review., Tech. Lit.*, 1961, **11**, Jan., 14) Failure of a water supply line in Canada is discussed. The hazard of $CaCl_2$ in prestressed concrete is noted.

**Some observations on the atmospheric corrosion product of steel** J. B. Harrison and T. C. K. Tickle (*Chem. Ind.*, 1960, (45), Nov. 5, 1383) Results of exposure at the Kirkby Industrial Estate, Liverpool, are presented, as pointing to a possible explanation of previously reported anomalies in ammonium pollution between Derby and Billingham, with their bearing on problems connected with atmospheric corrosion of steel.—S.H.-S.

**Pitting damage of steel plates** W. Dick (*Hüttenwerk Oberhausen Tech. Ber.*, 1955–58, paper 36; *Fachtechnischen Tagung über Tankerkorrosion der Schiffbautechnischen Ges.*, 1956, April, Hamburg, pp.11) The author deals with observations of pitting on ship steel plates, he discusses the causes and the theory of pitting, and means of protection against this type of corrosion. A change in the composition of the steel cannot be contemplated and, in the view of the author, there is no need for it (23 refs).—T.G.

**Pitting type corrosion in crude oil tankers** G. Becker and W. Dick (*Hüttenwerk Oberhausen. Tech. Ber.*, 1955–58, paper 37; reprint from *Schiff und Hafen*, 1957, (6), June, 510–518) The authors review characteristics of pitting type corrosion in general and in particular in crude oil takners. They also report laboratory tests on a variety of steels with respect to corrosion tests in stationary and flowing sea-water mixed with crude oil. The effect of hot-water jets, as used in the cleaning of the tanks after the discharge of the oil, on pitting corrosion is also dealt with. As a matter of fact this cleaning operation is for various reasons the main cause of pitting. Careful cleaning can do a lot to minimize the attack (80 refs).—T.G.

**Sea-water corrosion of unprotected ship-building steel** (*Hüttenwerk Oberhausen, Tech. Ber.*, 1955–58, paper 35; no source given, 1956, Aug., pp.5) Tests carried out by BISRA and by Hüttenwerk Oberhausen showed that the corrosion rate of plain carbon steels in sea-water does not depend on chemical composition. Only when the Cr level is raised to about 3% was a marked reduction in corrosion observed, but then pitting increased.—T.G.

**Some problems of corrosion in transport** V. G. Paranjpe (*Tisco*, 1960, **7**, Oct., 294–308) Corrosion in design of power plant, rolling stock and permanent way, car bodies, ships and tankers, and in aircraft is discussed (42 refs).

**Bacterial slime and corrosion in petroleum product storage** R. J. De Gray and L. N. Killian (*Ind. Eng. Chem.*, 1960, **52**, Dec., 58A–60A) A study of the growth of micro-organism and their effects is reported. Some rust inhibitors encourage growth. Some borate esters were fairly effective as bactericides.

**Internal corrosion of power station boilers** E. C. Potter (*Brit. Power Eng.*, 1960, **2**, Dec., 31–33) Modes of cracking and pitting and the formation and failure of protective oxide coatings are discussed in general terms.

**The corrosion problem in the gas industry** L. T. Minchin (*Coke Gas*, 1960, **22**, Dec., 530–534) A review of the symposium by the Inst. Gas Eng. and Soc. Chem. Ind.

**Polarization studies of mild steel in cultures of sulphate-reducing bacteria** G. H. Booth and A. K. Tiller (*Trans. Farad. Soc.*, 1960, **56**, Nov., 1689–1696) Cathodic and anodic polarization curves have been obtained for mild-steel electrodes in pure cultures of two species of sulphate-reducing bacteria, only one of which contains a hydrogenase capable of effecting the reduction of sulphate with hydrogen. Both organisms are shown to cause anodic stimulation by the production of sulphide ions, followed by anodic polarization due to the formation of partially protective sulphide films. Only the organism containing hydrogenase is able to influence cathodic polarization. The results are discussed in relation to theories of anaerobic corrosion of metals (13 refs).—C.F.C.

**Inhibition of $HNO_3$–HF corrosion of type 304–L stainless steel with $Al(NO_3)_3$, $9H_2O$** W. L. Walker (*HW–53636*, 1957, Nov., pp.3; from *Nucl. Sci. Abs.*, 1960, **14**, Jan. 15, 80) To prevent corrosion of equipment by $HNO_3$–HF mixture, aluminium nitrate monohydrate is added to tie up the fluoride, either as aluminium fluoride or a tight complex. It was found that a solution of $HNO_3$–HF, and $Al(NO_3)_3$, $H_2O$ in which the HF:$Al(NO_3)_3$, $H_2O$ molar ratio is 3, did not show serious corrosive attack on 300-series stainless steel.—R.S.F.C.

**Protection against corrosion** (*Assoc. Belge l'emploi Mat. Protection Contre Corr. II. Rapport Technique*, 1959, June, 1–81) The report deals with corrosion research work in progress during 1958. The method used for evaluating percentage of corrosion is given. Co-operative research on atmospheric, marine corrosion, and corrosion of unprotected structural steels is described and results are discussed in detail.

**Corrosion problems and their treatment. (3)** (*Corros. Prev.*, 1960, **7**, Nov., *Corrosion Eng. Section*, i–v, vii) A brief review of pipeline corrosion and protection.—C.V.

**Corrosion prevention. III** T. H. Turner (*Corros. Prev.*, 1960, **7**, Nov., 44–47) The nature of the work undertaken by the more important research organizations relating to corrosion problems is further discussed.—C.V.

**Methods of measurement in cathodic corrosion protection** K. Thalhofer (*Korrosion II, Kathodischer korrosionschutz*, Verlag Chemie, 1959, 158–181) Methods of measurement and instruments are described, and their applications discussed critically.

**Corrosion resistance of austenitic steels after pressure treatment at low temperatures** N. N. Lyulicheva and N. V. Pisareva (*Izvest. VUZ Chern. Met.*, 1960, (2), 78–80) The improvement in the resistance to corrosion of an austenitic steel with an increased proportion of martensite (above 50%) after rolling at low temp. points to the fact that low alloyed martensite imparts a rather high corrosion resistance. Austenitic steels with unstable austenite, when worked by pressure at low temp. in order to increase their strength, do not therefore deteriorate to any extent in their anti-corrosion properties.

**Soil corrosion of oil gas gathering lines in Alberta** R. G. Powell and G. G. Mainland (*Can. Min. Met. Bull.*, 1960, **53**, Sept., 713–717) Corrosion conditions and protection by coatings and cathodically are described.

**Anodic or cathodic? A problem in corrosion engineering** O. de Waele (*Corros. Prev.*, 1960, **7**, Dec., i–ii, viii) Areas of low resistivity are associated with the anodic regions, the potential shift, after the application of the cathodic protection is related to the natural potential. With the suppression of local corrosion cells, the impressed potential curve flattens out and to obtain full protection at the cathodic areas, the anodic ones become overprotected while full protection is only achieved when the local cathodes are polarized to the open circuit potential of the anodes. The anodic areas on unprotected structures are associated with the more negative potentials.—C.V.

**Conditions for the cathodic protection of metals** M. Pourbaix (*Corros. Prev.*, 1960, **7**, Dec., 43–48) If cathodic protection is correctly carried out it brings about a complete suppression of corrosion. It can be applied to all structure, immersed or buried in a corrosive medium, the sole condition being the ability to reduce the electrode potential permanently to the protective value and this at all points of the structure.—C.V.

**Corrosion prevention. IV** T. H. Turner (*Corros. Prev.*, 1960, **7**, Dec., 40–42) A brief review of the work and publications of the Tin Research Institute, the Zinc Development Association, Mond Nickel Co. Ltd, the Bureau of Standards, the DSIR organizations, and other sources.—C.V.

**Internal cathodic protection. VII. Lime anodes in cylindrical tanks. The edge effect** C. Plumpton and C. L. Wilson (*Corros. Prev.*, 1960, **7**, Dec., 33–36, 60) The mathematical theory is presented and discussed. The mechanical difficulties in mounting a series of line anodes co-axially in a long pipeline and the small gain in current spread likely to be given by short line anodes shows that little is to be gained by this approach. The best solution would appear to be small anodes, evenly spaced along the axis and this conclusion holds for both coated and uncoated lines.—C.V.

**On cathodic protection in cavitation damage** M. S. Plesset (*Trans. ASME*, 1960, **82D**, Dec., 808–820) A study of the effects of cathodic currents on cavitation damage. A series of tests in salt water showed a reduction in cavitation weight loss for all the materials examined when the test specimen was made the cathode of an electrolytic cell and gas was evolved at the specimen surface. This protective effect against cavitation damage increased with increasing magnitude of the cathodic current. A similar effect was observed when the specimen was made the anode in a test liquid of buffered distilled water when the gas at the specimen surface was oxygen. In a series of tests in which the voltage applied to the cell was reduced to a level at which no gas was evolved on the surface there was no protective effect with the specimen cathodic or anodic.—S.H.-S.

## ANALYSIS

**The development of iron and steel chemistry, its success and its aspects** F. Kordon (*Hüttenwerk Oberhausen, Tech. Ber.*, 1955–58, paper 39, pp.9; no source given) The development of iron and steel chemistry from the classic gravimetric and titrimetric methods to the application of modern automats for carrying out the analyses is reviewed (32 refs).—T.G.

**Determination of gases in metals by the vacuum fusion process using a gas chromatograph** R. Lesser and H. Gruber (*Z. Metallk.*, 1960, **51**, Sept., 495–501) In the newly-developed method described, $H_2$, $N_2$, and $O_2$ can be determined in steel and a number of high-melting point non-ferrous alloys. The graphite crucible is heated by means of a HF generator, and the gases are analysed by a high-sensitivity gas chromatograph (31 refs).

**On a sampling method for determination of gaseous elements in molten steel during the oxidizing process** H. Shigematsu and S. Furuta (*Nippon Kinzoku*, 1960, **24**, (6), 359–363) A spoonful is taken and killed, in a slag-coated ladle, with Al wire, and the sample is then sucked up through a 6 mm silica tube.

**Carbon control gives old axles new appeal** R. Davenport (*Steel*, 1960, **147**, Dec. 26, 80–81) Spark testers, enable sorting and classification of old axles from scrapped railroad cars, for re-use in a variety of products for industry, after heating to about 2250°F in a continuous reheating furnace and rolling into finished shapes on a cross-country mill. Numerous products and suggested fields for their use are described.—S.H.-S.

**Extraction and flame photometric determination of iron** O. Menis and T. C. Rains (*Anal. Chem.*, 1960, **32**, Dec., 1837–1841) Iron is extracted with 4-methylpentan-2-one (methyl *iso*butyl ketone) from 6 M HCl, and emissivity is measured at 372 mμ.

**Determination of ferrous iron in the presence of ferric iron with bathophenanthroline** G. F. Lee and W. Stumm (*J. Am. Water Works Assoc.*, 1960, **52**, Dec., 1567–1574) The 1, 10-phenanthroline method is apt to provide incorrect results unless the test is carried out under special conditions. The new reagent, 4,7-diphenyl-1,10-phenanthroline is more sensitive, the complex formed can be extracted by immiscible solvents (*iso*amyl alcohol, nitrobenzene, etc.), and this procedure renders the method less liable to interference. At the moment, this reagent is expensive but a method of recovery is suggested.

**Macro- and microdetermination of traces of cobalt. Spectrophotometric and polarographic determination in steels MA 2B Edelweiss** D. Monnier, W. Haerdi, and J. Vogel (*Anal. Chim. Acta*, 1960, **23**, Dec., 577–584) [In French] Stainless steels of 18–8 type are analysed using either 0·1–0·5 g or 1 mg samples using exchange resin separation.

**Spectrophotometric determination of chromium (III) with EDTA** F. Den Boef, W. J. De Jong, G. C. Krijn, and H. Poppe (*Anal. Chim. Acta*, 1960, **23**, Dec., 557–564) A separation only interfered with by Ni is described.

**The polarographic determination of niobium in highly alloyed steels** D. J. Brindley (*Analyst*, 1960, **85**, Dec., 877–883) Up to 3%Nb can be determined by separation as niobic acid, KOH fusion, and polarography at pH 1·9. If Mo is present a solvent extraction is necessary.

**Determination of tungsten and molybdenum without separation** E. Lassner and R. Scharf (*Planseeber*, 1960, **8**, Dec., 130–133) A double titration or a titration and a photometric measurement are used.

**Chelometric titration of manganese in ferromanganese** A. G. C. Morris (*Chem.-Analyst.*, 1960, **49**, Dec., 105–106) The EDTA test of Přibil and Kopanica was considered unwieldy for control purposes; this has been modified and gives accurate results simply and speedily.

**Chelometric titration of manganese in ferromanganese** K. Studlar (*Chem.-Analyst.*, 1960, **49**, Dec., 106–107) The EDTA test of Přibil and Kopanica is discussed and compared with the Volhard method. Even 2%Cu does not interfere but large amounts of Ni, Zn, and Pb cause a sluggish end-point. The use of 0·025 M EDTA improves the accuracy of the titration as compared with that attained with 0·05 M; this reagent should be standardized against ferromanganese rather than against Pb, otherwise high results are obtained.—C.V.

**A new rapid method for the determination of nickel in ferrous and ferromagnetic metals** C. L. Luke (*Anal. Chem.*, 1961, **33**, Jan., 96–97) The Ni is precipitated as hexamminoperchlorate and then titrated by the cyanide method. Several NBS standard steel and Ni-base alloys were analysed using 0·2 g samples and close agreement was obtained.—C.V.

**Extraction of zirconium with di-*n*-butyl phosphate and direct determination in the organic phase with 1-(2-pyridylazo)-2-naphthol: Application to fluoride solutions** R. F. Rolf (*Anal. Chem.*, 1961, **33**, Jan., 125–128) This method is directed to the determination of microgram quantities of Zr in Al–Mg alloys and consists of dissolving the alloy in a mixture of mineral acids and fluoboric acid. $Al(NO_3)_3$ is used to complex the fluoride and the Zr is quantitatively extracted with di-*n*-butyl phosphate in $CHCl_3$. The addition of an alcoholic solution of 1-(2-pyridylazo)-2-naphthol gives an intense red colour. The error is ±2% and the advantage of this over other methods is that the fluoride can be used to ensure complete dissolution but does not interfere with the determination.—C.V.

**Determination of aluminium and sulphur in ferro-molybdenum** Y. Kakita, E. Sudo, and M. Namiki (*Nippon Kinzoku*, 1960, **24**, (6), 353–366) Fe and Mo are removed with methyl *iso*butyl ketone and Al is then determined with oxine. S is determined as $BaSO_4$.

**A suggested amperometric titration method for determining dissolved oxygen** E. Goldman and B. Dietz (*J. Am. Water Works Assoc.*, 1960, **52**, Dec., 1575–1576) The principles, advantages, and disadvantages of the Winkler and amperometric methods are briefly summarized. The apparatus, reagents, and procedure is described a standard phenylarsenoxide being used for the end-point titration, the number of ml used being recorded. In the calculation it is shown that the ppm dissolved oxygen = 4·51 × ml phenylarsenoxide.—C.V.

**Determination of arsenic, antimony and tin in pig-irons and steels by means of the radioactive indicators** S. Gomišček (*Nova Proizv.*, 1960, (5), 273–275) The article deals with details of the work which includes development of the analytical process for determination of As, Sb, and Sn in pig-irons and steels. Treats the distillation of the As, Sb, and Sn chlorides and bromides respectively by the radioactive isotopes $^{76}As$, $^{124}Sb$, and $^{113}Sn$ and determined the most convenient conditions for their distillation. Application of radioactive indicators has considerably facilitated this work, shortened its duration, and increased the accuracy of the results obtained.

**Faint lines in the arc spectrum of iron (Fe I)** C. C. Kiess, V. C. Rubin, and C. E. Moore (*J. Res. NBS*, 1961, **65A**, Jan.–Feb., 1–29) Spectrograms taken with an arc-in-air as source over a range 2102–8679 A were examined. Twelve new energy levels were found resulting in a total of 121 classified lines and a table is given showing 698 classified lines; these include many whose wavelengths had been predicted as combinations among the known energy levels and found in the solar spectrum and a list of 1102 newly measured unclassified lines is provided and comparison can be made with the findings of other observers. A comparison of the new lines with the solar spectrum has resulted in the identification of 306 solar lines of Fe I unblended and of 85 as blends to which Fe I is a contributor.—C.V.

**Spectrum analysis in an American cupola-converter steelworks** (*Iron Coal Trades Rev.*, 1960, **181**, Dec. 23, 1355–1358) Use of a Baird-Atomic direct reading spectrograph at Acme Steel is described.

**Spectrometer speeds analysis at up-to-date steel mill** (*Iron Age*, 1960, **186**, Oct. 20, 162–163) The use of a Baird-Atomic spectrometer is described whereby a given heat can be analysed and a report returned to the operating team within 6 min, checking all elements except carbon and slag on a round-the-clock basis and enabling a combination of speed and flexibility allied to high quality control.

**X-Ray spectrographic determination of zirconium, tungsten, vanadium, iron, titanium, tantalum and niobium oxides: Application of the correction factor method** B. J. Mitchell (*Anal. Chem.*, 1960, **32**, Nov., 1652–1656).

**Determination of available oxygen in manganese ores by cerate oxidimetry** D. G. Foster (*Anal. Chem.*, 1961, **33**, Jan., 146) 0·1 N arsenious acid in $H_2SO_4$ and a 0·1 N solution of $NH_4$ sulphatocerate in $H_2SO_4$ are used, the cerate being standardized with arsenite solution using three drops 0·01 M $OsO_4$ solution as catalyst and one drop Ferroin as indicator. Suitable samples of ore are weighed into 1–2 conical flasks and about 45 ml of the arsenious acid solution run in from the burette; 10 ml concentrated $H_2SO_4$ is added and the whole gently boiled till no coloured particles remain; the solution is diluted with 100 ml water, cooled, and three-drops $OsO_4$ + one drop Ferroin added; the whole is back titrated with the cerate solution to the pale blue end-point.

**Fractional determination of metallic iron in reduced manganese ores** S. Watanabe (*Nippon Kinzoku*, 1960, **24**, (6), 343–346) $CuCl_2$ in methanol was tested, the extract being treated with Al and the iron titrated with $KMnO_4$.

**Fractional determination of manganese monoxide in reduced manganese ores** S. Watanabe (*Nippon Kinzoku*, 1960, **24**, (6), 346–350) The residue from the $CuCl_2$/MeOH treatment treated with $(NH_4)_2SO_4$ in a stream of $CO_2$ dissolves the MnO. This is determined with persulphate/permanganate.

**The micro-determination of ferrous iron in silicate minerals by a volumetric and a colorimetric method** A. D. Wilson (*Analyst*, 1960, **85**, Nov., 823–827) Quiquevalent V in HF is used.

**A rapid flame-photometric method for the determination of $Na_2O$ and $K_2O$ in various refractories** K. Konopicky and W Schmidt (**Ber. Deutschen Keram. Ges.*, 1960, Aug., 368–371) Quantitative extraction with HF is followed by determination on a Beckmann DU spectrophotometer in a $H_2$–$O_2$ flame.

**The determination of fluorine in cupola slags** H. Green (*BCIRA J.*, 1960, **8**, Nov., 838–843) A spectrophotometric method using Al and an aluminium-aluminon reagent is described.

**Determination of calcium and magnesium in high-manganese welding fluxes** P. Provondra and R. Přibil (*Chem.-Analyst*, 1960, **49**, Dec., 109–110) Mixtures of Mn silicates and alkaline earth metals are used as welding fluxes and the Mg–Ca content and ratio to Mn should be rapidly determinable. With a high Mn content, the Mn must be removed before Ca and Mg are determined; the hydroxide or sulphide precipitation is considered to be too slow. $Mn^{2+}$ forms a stable complex at pH 3·8 with diaminocyclohexanetetra-acetic acid (DCYTA) but Ca and Mg do not react and thus can be separated by passage through a strongly acidic cation exchange resin and after elution can be determined by appropriate EDTA titration.

**Free cyanide analysis of copper cyanide plating solutions** J. R. Crain (*Plating*, 1960, **47**, Sept., 1032–1037) Free cyanide has been determined with change of concentration of the components and temp. of the solutions; dilution of solutions containing complex ions increases free cyanide as the complex ions partially dissociate; with increase in temp. free cyanide increases as the $Cu^+$-complex ions are partly dissociated and it is shown that cyanide plating solutions prepared to contain 0·5, 1·0, 1·5 oz/gal free cyanide will actually contain ~3·0, 3·5, 4·0 oz/gal free cyanide at a solution temp. 75°. Though control of the free cyanide content of a plating solution is possible by the room temp. method, greater precision is attainable with the cold method.—C.V.

## INDUSTRIAL USES AND APPLICATIONS

**Cold-worked stainless fastener reduces design problems** Huck Manfg. Co. (*Iron Age*, 1960, **186**, Oct. 13, 92–93) Fastener belts of type 304 stainless steel for which high strengths and corrosion resistance preparation are claimed, while eliminating need for heat treatment and using copper plating as lubricant in cold-headed applications involving small dia. fasteners, are presented.—S.H.-S.

**New freedom in casting design achieved with stainless steel braid** Howard Foundry Co. (*Wire Wire Prod.*, 1960, **35**, June, 741, 782) Stainless steel braid is used for coring in Mg alloy castings.

**Flexible metal tapes for high-speed mechanisms** C. B. Hebeler (*Prod. Eng.*, 1961, **32**, Feb. 20, 65–69) The problem of accurate transfer of motion between remote linage elements is considered in precision mechanisms; it should

have low weight with high strength and be fatigue resistant. Flexible steel tapes are considered and several examples are given and are illustrated. The composition, physical properties, and constants for these tapes are given.

**Stainless steel for cutlery** M. Tagaya and K. Kishi (*Osaka Univ. Fac. Eng. Techn. Rep.*, 1960, **10**, March, 481–487) The authors studied the optimum chemical compositions, hot-working, and heat-treatments to produce stainless steel cutlery of good cutting ability and great durability. They also studied the machinability of steels for cutlery and found that high-carbon stainless steels had much higher machinability than low-carbon ferritic stainless steels.—R.S.F.C.

**High silicon iron mine pumps** H. Sawamura, O. Murase, O. Tajima, and K. Akamatsu (*Suiyokwai-Shi*, 1958, **13**, April, 393–398) It has been thought that high-silicon iron is hard and brittle and that it is an unsuitable material for machines which have to be used under high pressure and with rough treatment as in mine pumps. However, with proper design high-silicon iron can exhibit its special character in which it is superior to any other material. The authors report progress on how the mine pump, made of silicon iron, has been developed.

**Ferritic alloy steels for power plant** M. G. Gemmill (*Alloy Met. Rev.*, 1960, **9**, Dec., 2–8) A survey in terms of historical development, service experience, and selection factors and design stresses is presented.

**Wear and tear of high-manganese steel plates in cement mills** G. Mussgnug (*Hüttenwerk Oberhausen, Tech. Ber.*, 1955–58, paper 42; no source given, pp.8) Tests carried out in two cement mills with high-Mn steel grinding plates showed that the wear and tear can be very different even of the same material. The decisive factor for long service life is the structure of the steel, it must be austenitic. Of further importance are the ratios Mn:C, Mn:Si + C, but particularly that of Mn:Si. The relationship between the Mn:Si ratio and wear has been established: with increasing Mn:Si wear diminishes almost linearly.—T.G.

**Experience with the 20KhGR cemented boron steel for motor car parts** A. M. Tarasov (*Stal'*, 1961, (1), 64–68) This low-alloy Cr–Mn–B steel has been proved to be a satisfactory replacement for expensive high-alloy grades. Its further uses are indicated.

**Design guide for stainless honeycomb sandwich panels** (*Prod. Eng.*, 1960, **31**, Dec. 5, 67–72) Details of construction and tables of mechanical properties are given.

**Nature of light gauge steel members under torsion** Y. Yokoo, S. Igarashi, and J. Sakamoto (*Proc. Symp. on Weightsaving of Bridges and Structures, Japan. Soc. Promotion of Science*, 1960, March, 86–100) A C-type light gauge steel member shows a twisting tendency when the load is applied in the plane of the web and causes large twisting deformation and additional stresses. This paper investigates this behaviour and discusses the deformation and strength of C-type steel members under combined torsion and flexure. On the results of these analyses the authors discuss the allowable deformation from a viewpoint of the strength and practical uses, and present two effective methods to prevent the excessive deformation and extreme increase of the normal stress.

**The development of design information for steel structures** J. A. Gilligan and R. F. Miller (*Reg. Tech. Meet. AISI*, 1958, 109–133) The results obtained by the following bodies are summarized: Battelle Memorial Institute, 'Determination of mechanical properties of steel for airframes', Franklin Institute, 'Buckling strength of type 301 stainless steel plates and girders', Engineering Foundation (Column Research Foundation) whose completed report has not yet been received although a general resumé is provided, Research Council on Riveted and Bolted Structural Joints and the Ship Structure Committee on 'Transition temperature of ship steels'. The results of this interchange of views and experience between the steel producers and these bodies, covering as they do such a wide field of endeavour, is one of the most valuable aspects of the envisaged programme (25 refs).—C.V.

**Plastic design of steel structures** L. S. Beedle (*Reg. Tech. Meet. AISI*, 1958, 393–421) An outline in general terms of the method.

**The use of galvanized sheet in modern architecture** G. Körner and E. Fösig (*Bänder-Bleche-Rohre*, 1960, Sept., 27–29) The authors review the corrosion behaviour of galvanized sheet as compared with unprotected steel. For architectural purposes the coating thickness varies between 0·50 and 1·50 mm. Recently galvanized strip has been made commercially available. Some applications of galvanized sheet in architecture are described and illustrated.—T.G.

**Stainless steel in architecture** (*Inco-Mond Mag.*, 1960, (16), 13–16) The headquarters of the Phoenix-Rheinrohr steel group in Düsseldorf makes wide use of 18/8 stainless steel cladding, in Toronto curtain-walling of 18/8 stainless steel and glass is used throughout a 14-storey building, and Detroit's National Bank has fully reversible stainless steel windows that can be cleaned from within. These are illustrated together with a wide selection of decorative Ni stainless steel finishes and an interior decoration of the entrance hall of the Centre d'Information du Nickel in Paris. The large double doors of Marconi House (18/10/2 Cr–Ni–Mo-stainless steel) are also shown.—C.V.

**Installation and handling of steel ropes in industrial uses** A. Brumat (*Zastita Mat.*, 1960, **8**, Nov., 513–518) This paper deals with various types of steel ropes, their construction, superiority of certain makes, and their use in industry and transportation.—C.F.C.

**Application and protection of steel ropes in industry and shipbuilding** B. Vajagic (*Zastita Mat.*, 1960, **8**, Nov., 492–495) Application of steel ropes for construction and manipulative purposes; various ways of production of steel ropes depending on intended purposes; quality of steel ropes for use in shipbuilding; ropes for lifting gears; protection of steel ropes against corrosive influences in shipbuilding and ineustry; tin coating of wires and testing the tin coating and ropes with hemp core, impregnation of stuffing and lubrication of steel ropes are considered.—C.F.C.

**Application and protection of steel ropes in mining** M. Antunovic-Koblißka (*Zastita Mat.*, 1960, **8**, Nov., 496–499) Types of steel ropes for use in mining; choice of ropes for lifting and conveyance devices; drilling equipments, digging machines, and other appliances; harmful chemical and mechanical influences to which steel ropes at mines are exposed; testing procedure for steel ropes on receipt and while in use at mines with particular consideration of lifting ropes; protective measures and treatments, and summary of existing rules regarding inspection and protection of steel ropes in mining are given.—C.F.C.

**Transportation and storage of steel ropes** B. Jovanovic (*Zastita Mat.*, 1960, **8**, Nov., 525–531) Description of the best-known protection systems of steel ropes in transport and storage; testing of various packaging forms before actual large production is accepted for shipping; risks and strains a shipment of steel rope generally has to encounter; how to load steel ropes on vehicles; proper marking in transportation and storage; insurance of various risks during the transportation and storage are all considered.—C.F.C.

## HISTORICAL

**The regenerative gas furnace of Siemens** M. Schofield (*Iron Coal Trades Rev.*, 1961, **182**, Jan. 20, 143–144) A brief historical review of the gas-producer and the regenerators that were later developed from 1861 onwards, from the first production of glass to its adoption by the iron, steel, and chemical industries.

**Seventieth birthday of V. N. Svechnikov, member of the USSR Acad. of Sci.** (*Stal'*, 1961, (1), 95).

## ECONOMICS AND STATISTICS

**The investment policy of an integrated iron and steel works** R. Graef (*Hüttenwerk Oberhausen, Tech. Ber.*, 1955–58; paper 1; reprint from *Der Volkswirt*, 1957, Oct. 25, 1–5) The investments required by the integrated iron- and steelworks of Oberhausen after the war and in the course of keeping the works at a high standard of efficiency and modernization are described. The works have been enlarged to an annual production of $2{\cdot}5–3\times10^6$ t, a size that it also regarded as economical in the USA.—T.G.

## MISCELLANEOUS

**Possibilities of raising yields in the wet extraction of vanadium** D. Trojka (*Hutn. Listy*, 1960, **15**, (10), 781–791) On the basis of laboratory and works experiments a number of measures leading to more efficient extraction of V are discussed.—P.F.

**Morphology of synthetic submicroscopic crystals of α- and γ-FeOOH and of γ-$Fe_2O_3$ prepared from FeOOH** G. W. van Oosterhout (*Acta Cryst.*, 1960, **13**, Nov. 10, 932–935).

**The crystal structure of stottite Fe [Ge(OH)$_4$]** H. Strunz and M. Giglio (*Acta Cryst.*, 1961, **14**, March, 205–208).

**Steam from organic waste** (*Inco-Mond Mag.*, 1960, (16), 10–11) This is generated in a 75-t reactor (68 ft long × 7 ft dia.), constructed of Type 316 Ni stainless steel (19/9 Cr–Ni–Mo). A mixture of pulp liquors under pressure is oxidized by compressed air and with the resulting exothermic reaction, heat is given off. The steam–gas mixture is continuously drawn off and passed to a steam turbine to produce power and thence to separators and heat exchangers to produce steam and hot water. Heat is required to commence the reaction; thereafter it is self-sustaining, the operating temp. being 260–315° with air and liquor pressures of 1400–1500 psi. The unit has a 95% efficiency.—C.V.

**The protection of metal structures against fire in the United States** K. R. Woods and F. A. Thulin jun. (*Acier Stahl Steel*, 1960, **25**, Dec., 533–535) Asbestos covering processes with the calculations for their resistance to fire are described.

**Survey of the technical and scientific uses of computers in the iron and steel industry** D. G. Owen and R. J. Taylor (*JISI*, 1961, **198**, Aug., 352–358) [This issue].

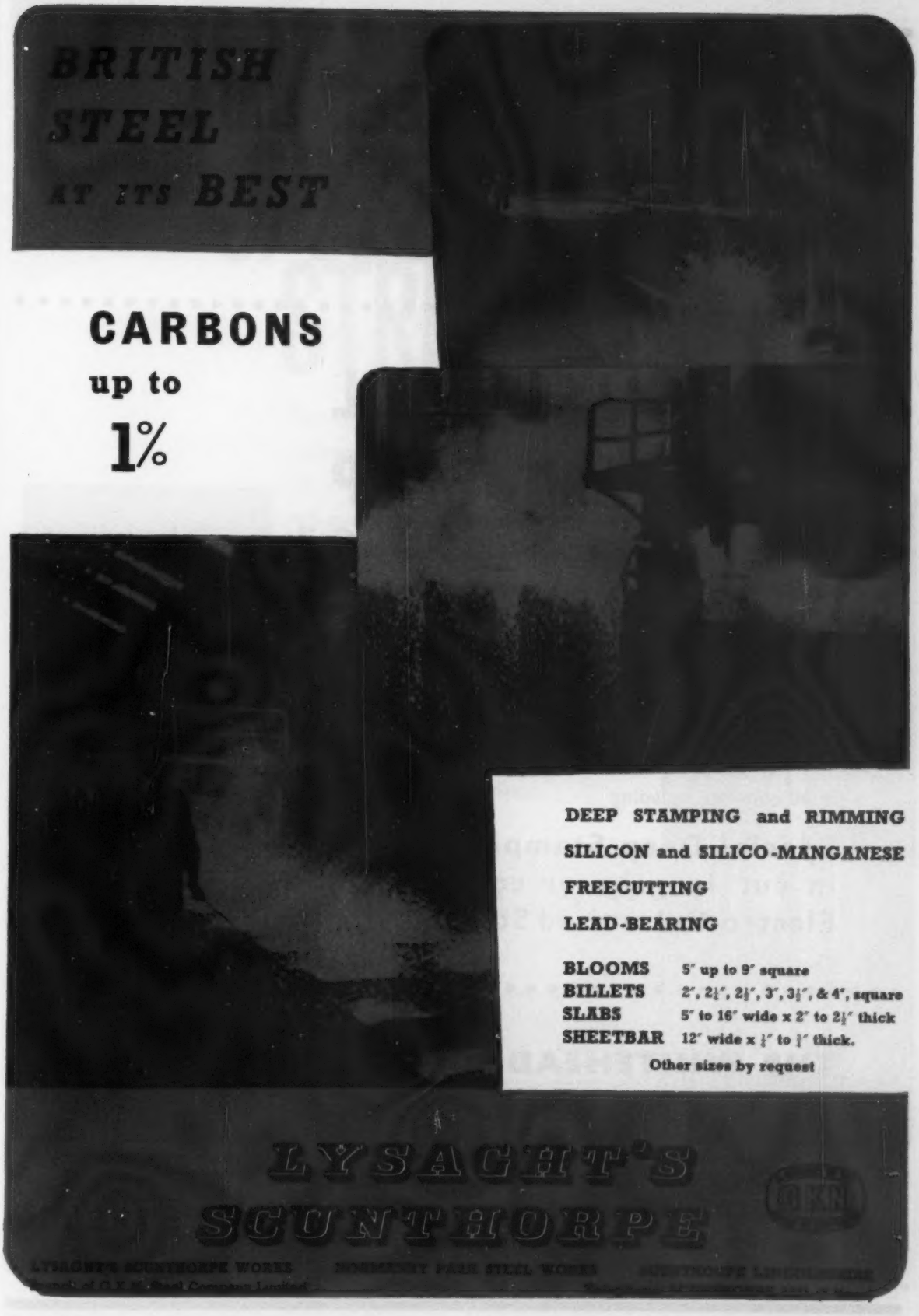
**Applying operational research in the steel industry** R. H. Collcutt (*Brit. Steel*, 1959, **25**, Dec., 414–417, 420–422) This approach is made to three aspects of the steel industry and it is pointed out that such enquiries need not be directed towards production. The cost of ship transport and unloading of ore were studied; the question as to whether a specified press shop (as yet unbuilt) would be more profitable than one of the existing hammer shops was examined and the general repair of OH furnaces was considered. In conclusion it is pointed out that the essentials are to define the problem, to select feasible alternative solutions, and to decide a suitable criterion for choosing between these. The actual technique of analysis may often be a secondary consideration.—C.V.

**Memomotion—a valuable work study technique** A. A. Timmins (*BCIRA J.*, 1960, **8**, Nov., 812–820) A process of time-lapse cinematography and its uses is described.

**A note on vanadium poisoning** G. V. James (*Analyst*, 1960, **85**, Nov., 851–852) Poisoning if two workmen engaged on chipping an incrustation from a tank was observed. The tank was used for treating bauxite with NaOH and 3·5%V was present in the incrustation.

**An introduction to pneumoconiosis. I. The cost of dust** G. MacBain (*Ironfounding Health and Safety*, 1960, 29–31) The question of diagnosis is discussed and it is shown that the man's health falls into one of four groups; these are examined.—C.V.

**The incidence of pneumoconiosis** G. F. Keatings (*Ironfounding Health and Safety*, 1960, 32–37) The figures presented by various workers for moulders, fettlers, and core-shop workers in Scotland, Midlands, and N.E. and N.W. England are discussed; incidence is highest in the fettler (6·7) and moulder (5·2) groups with the coreshop (3·1%). The questions of susceptibility *v.* environment, the approach of the doctor to the worker, and the age group are dealt with in the discussion.—C.V.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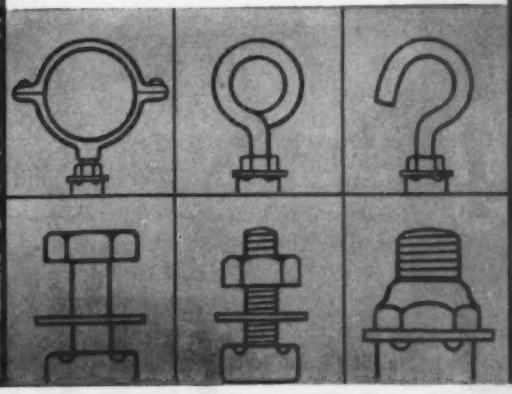

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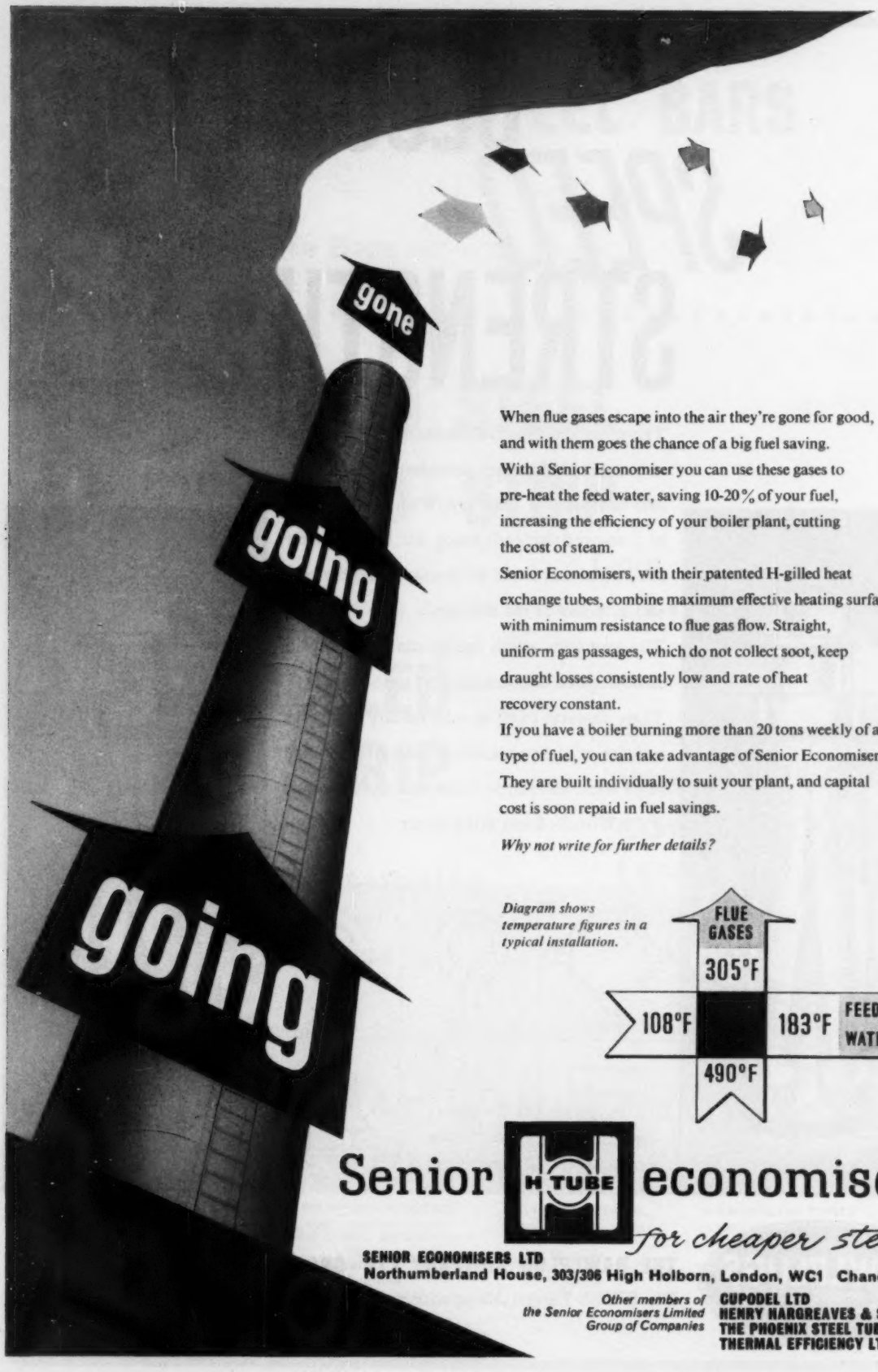


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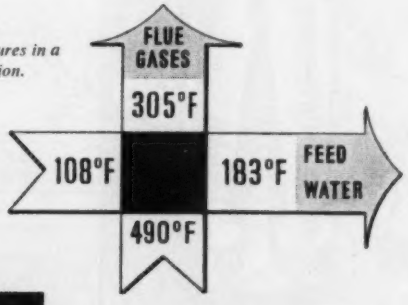


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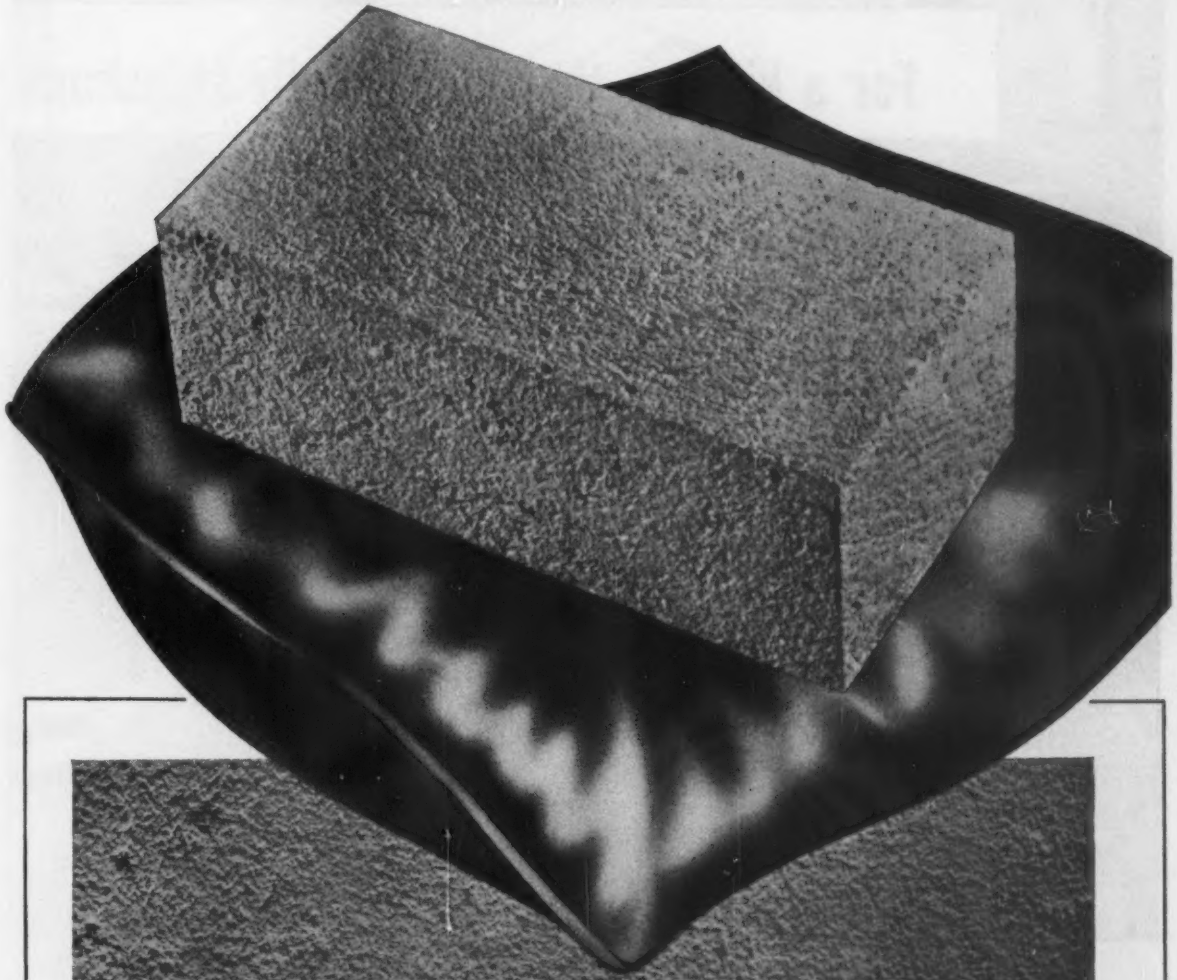

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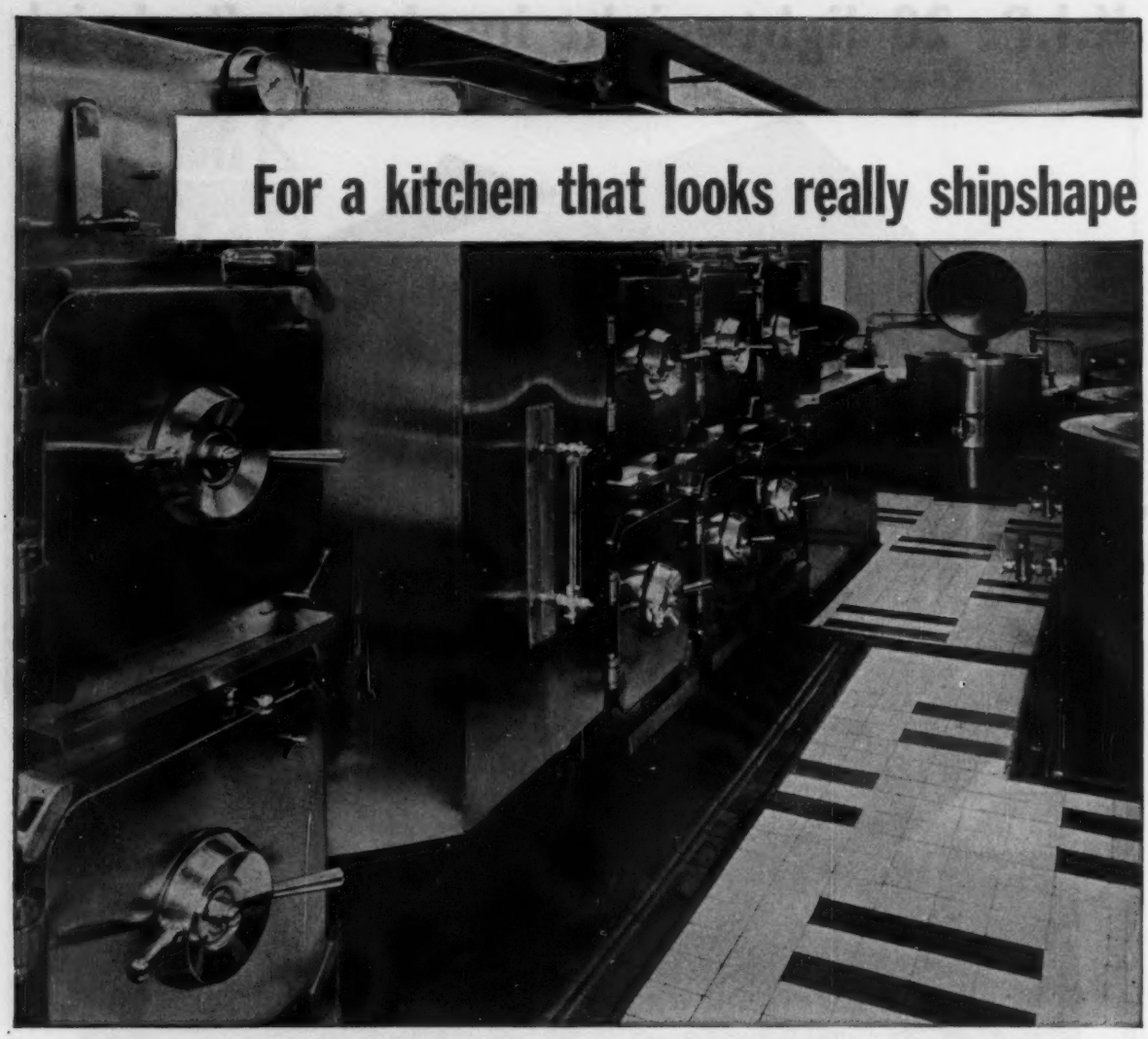

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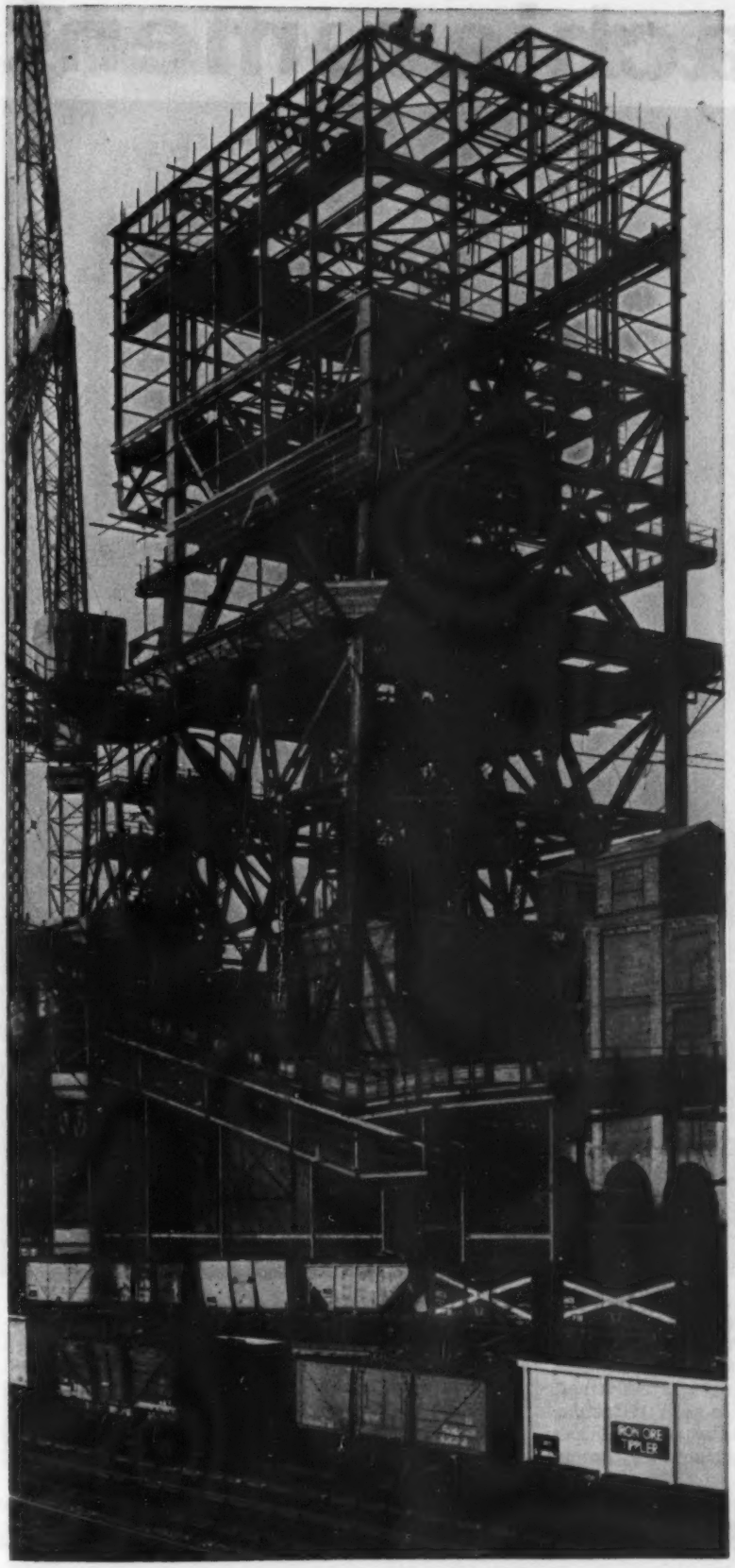


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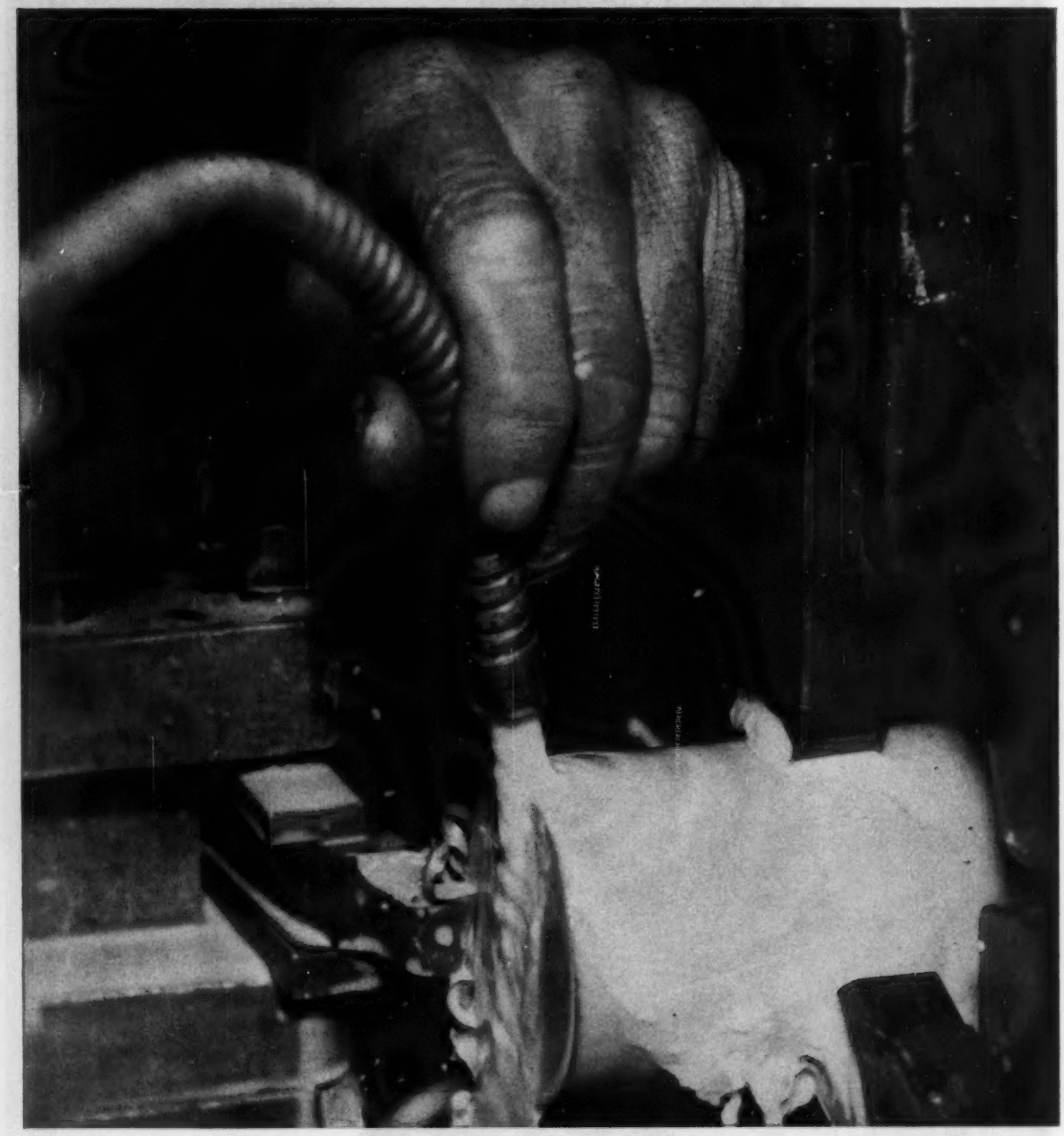

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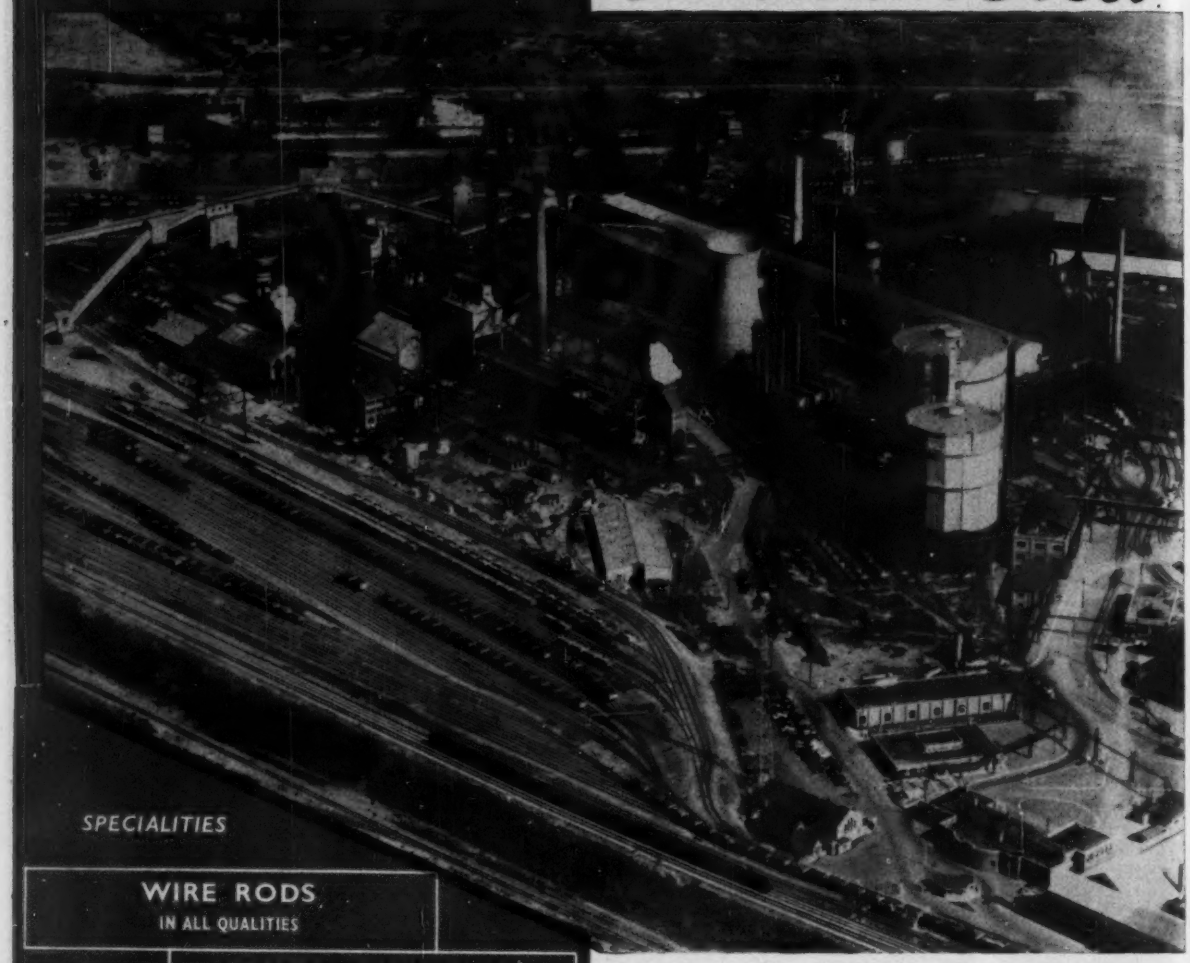

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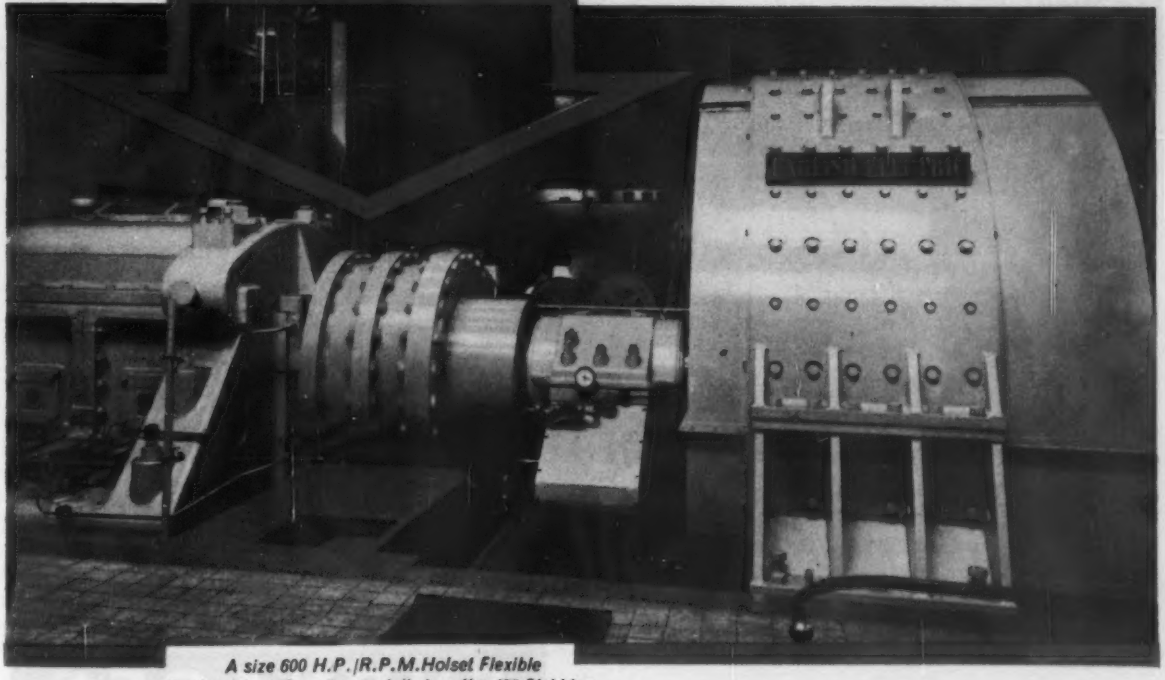

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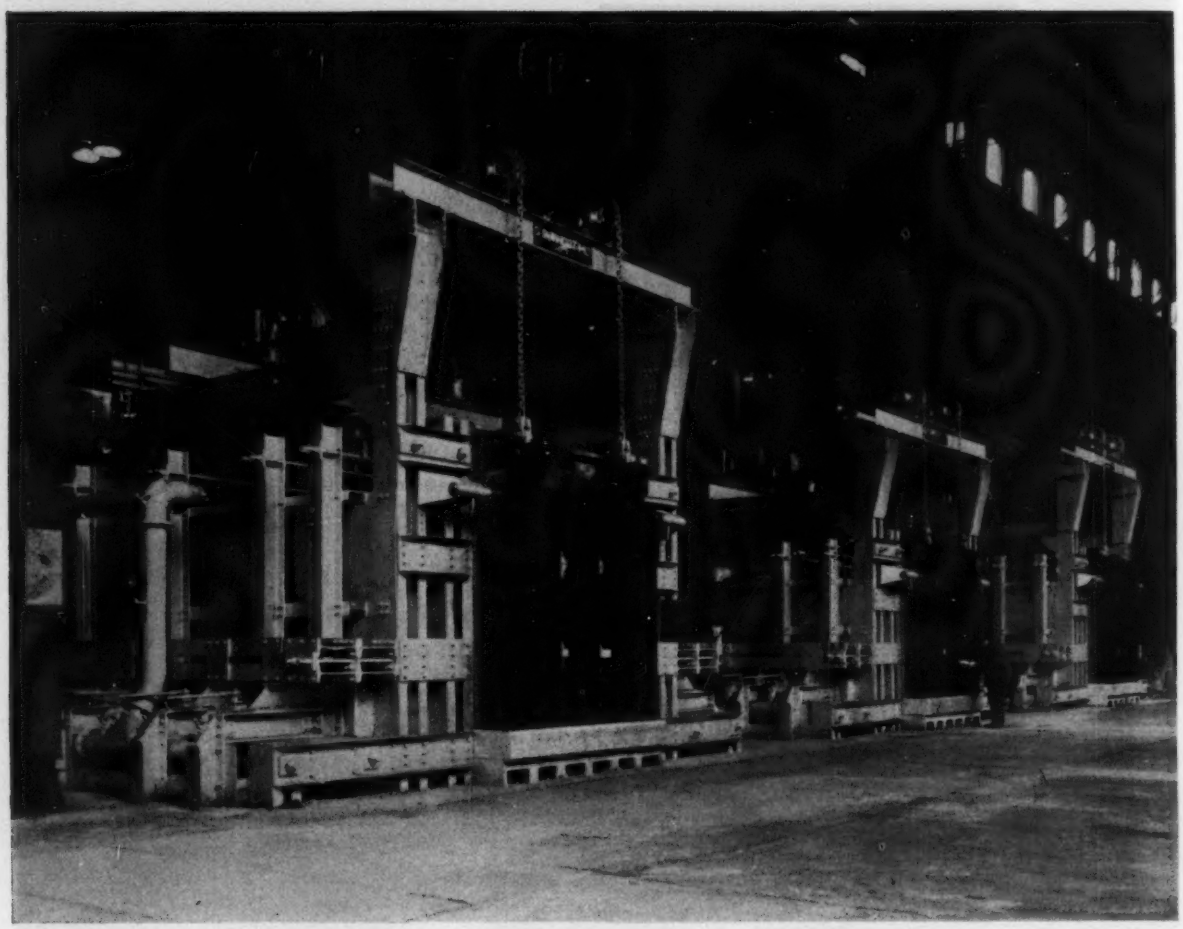

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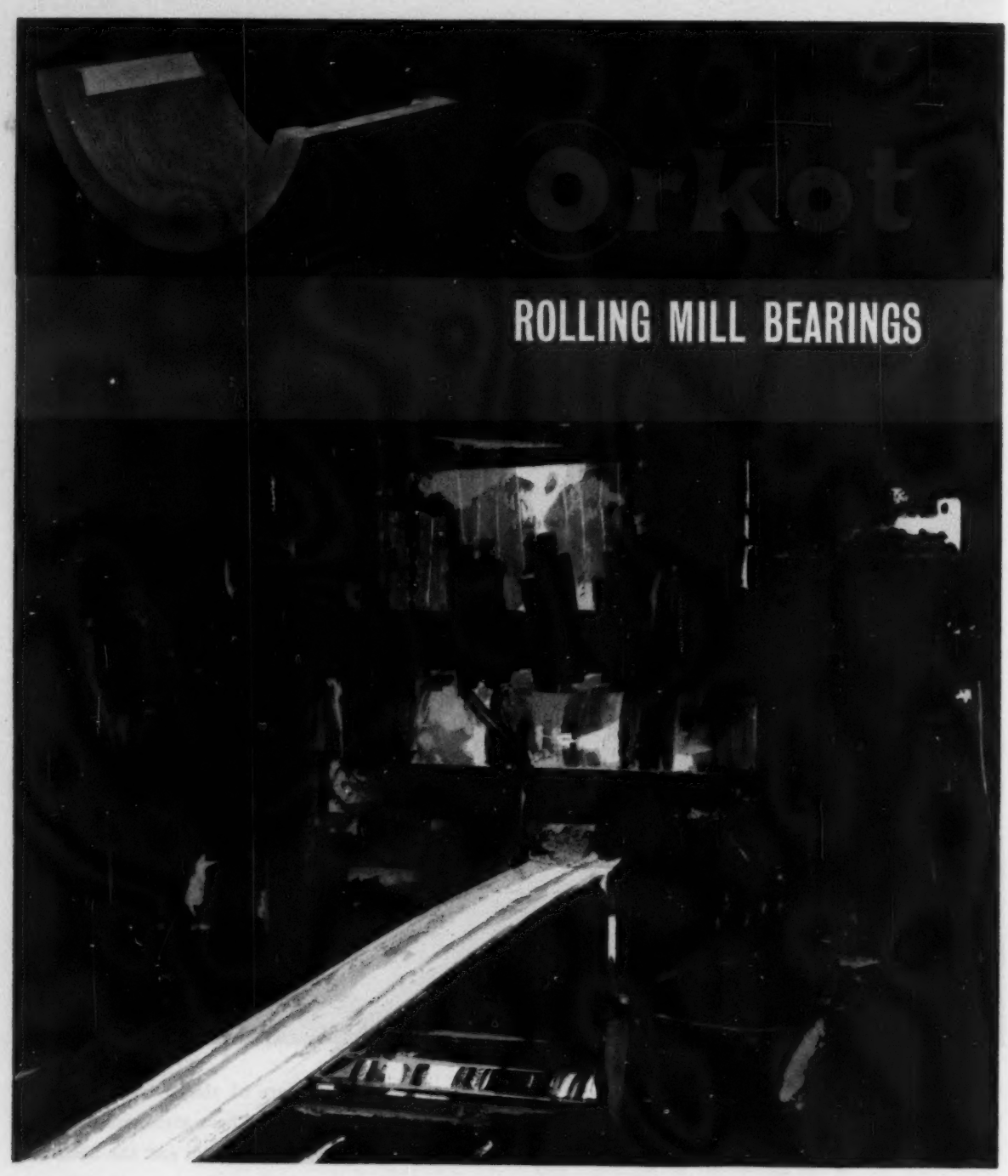


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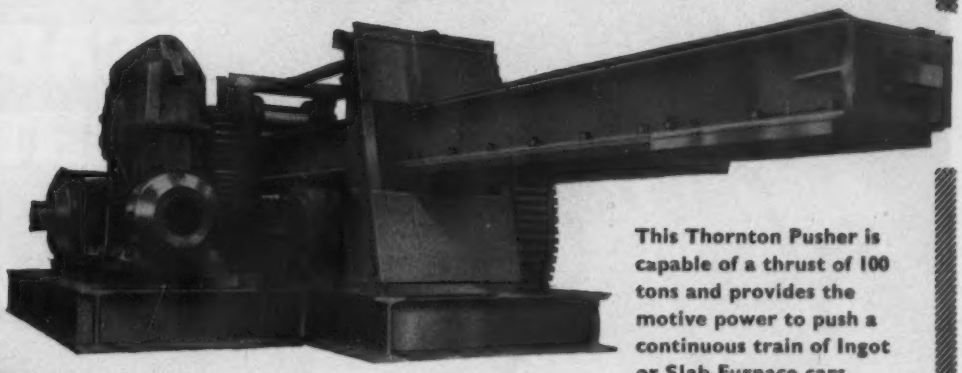

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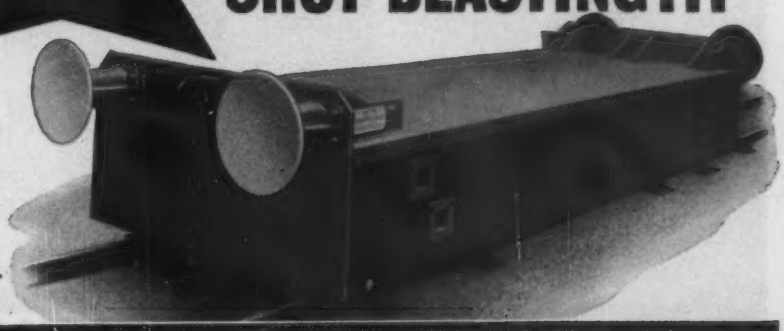

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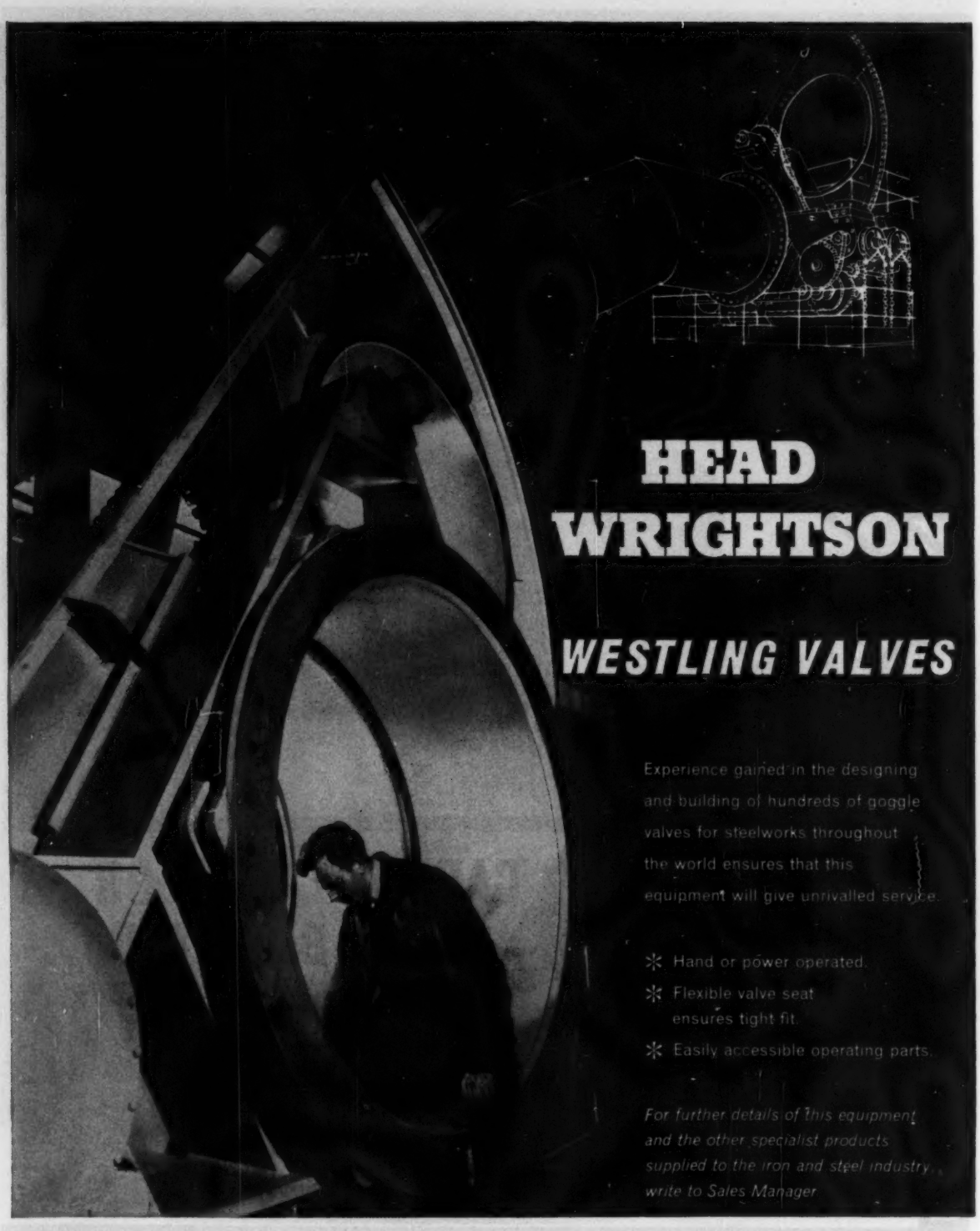
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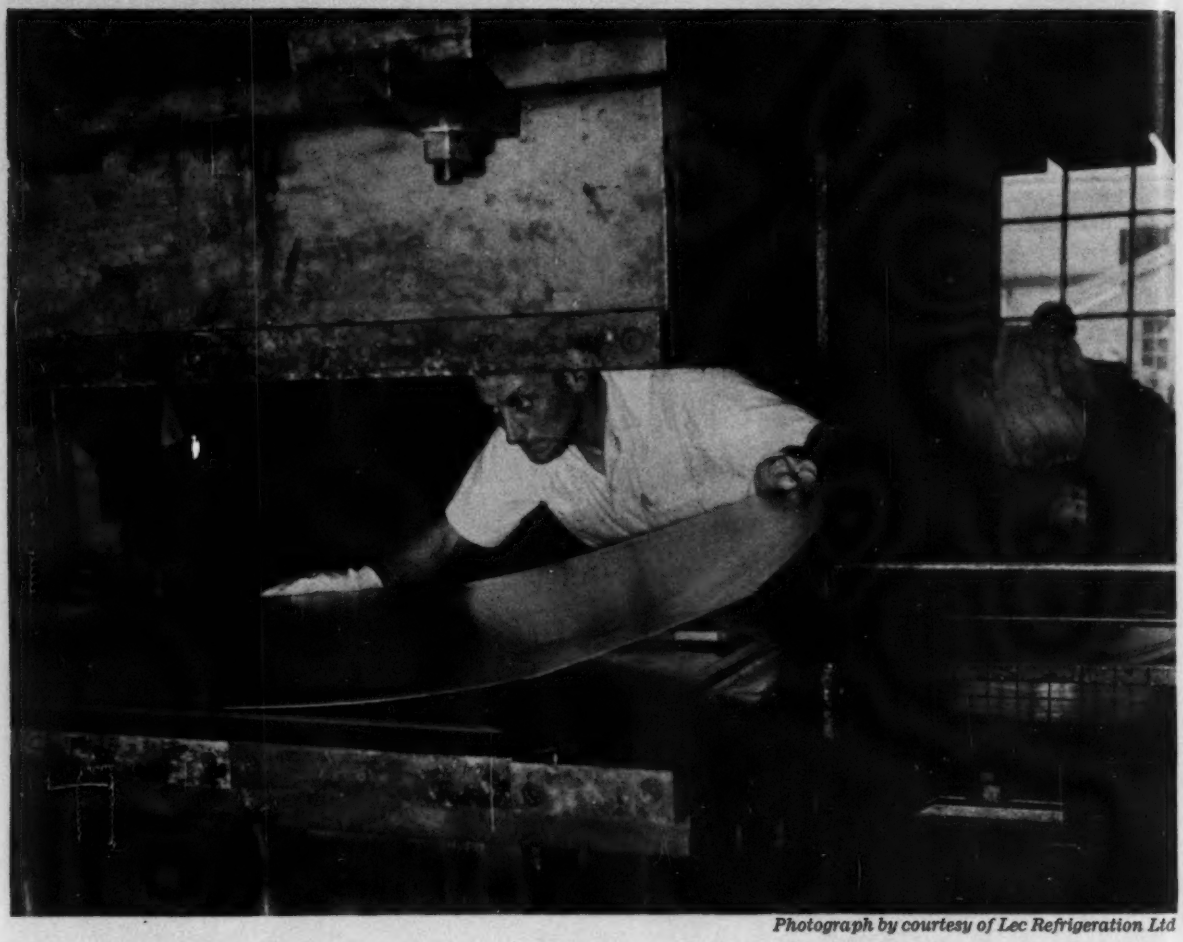

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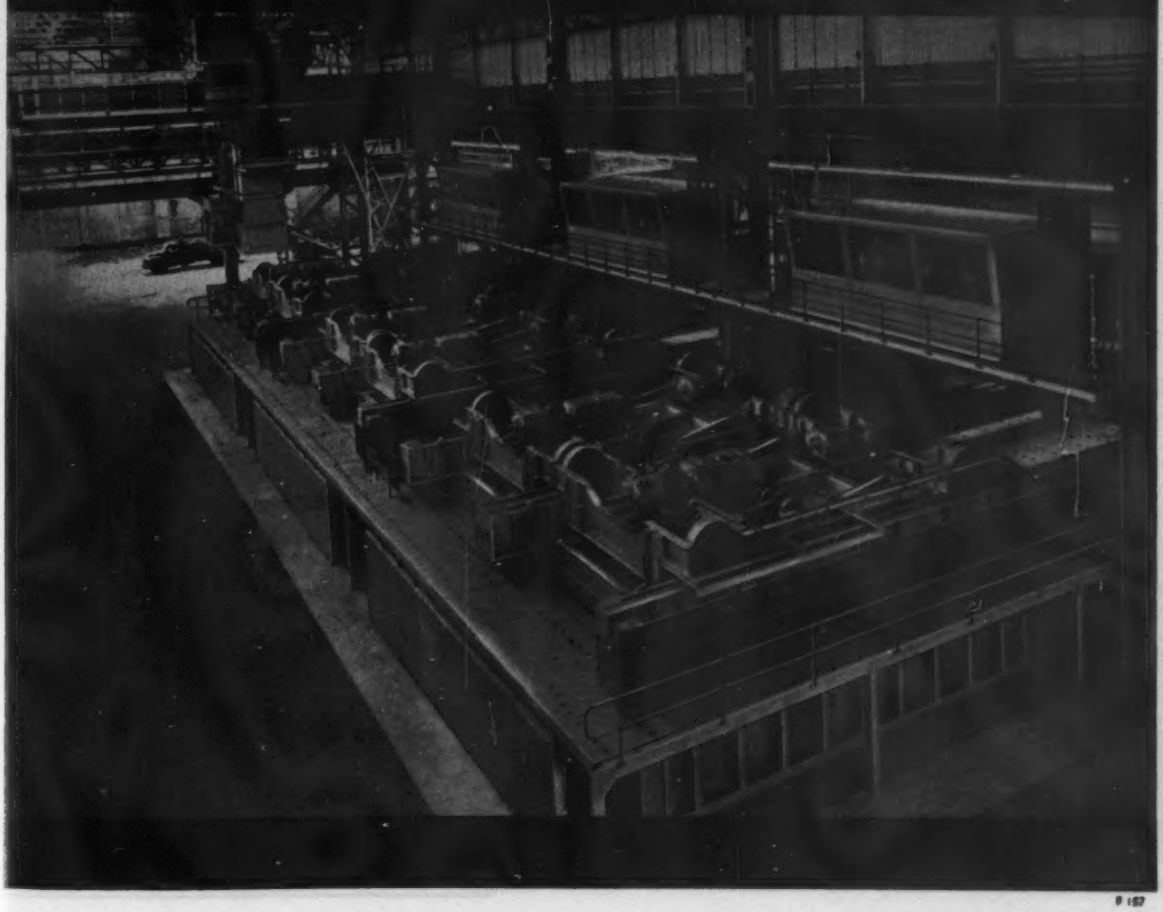

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Pouring Hot Metal in a 200 Ton Open Hearth Furnace, Abbey Works, The Steel Co. of Wales, by courtesy of whom this photograph is reproduced


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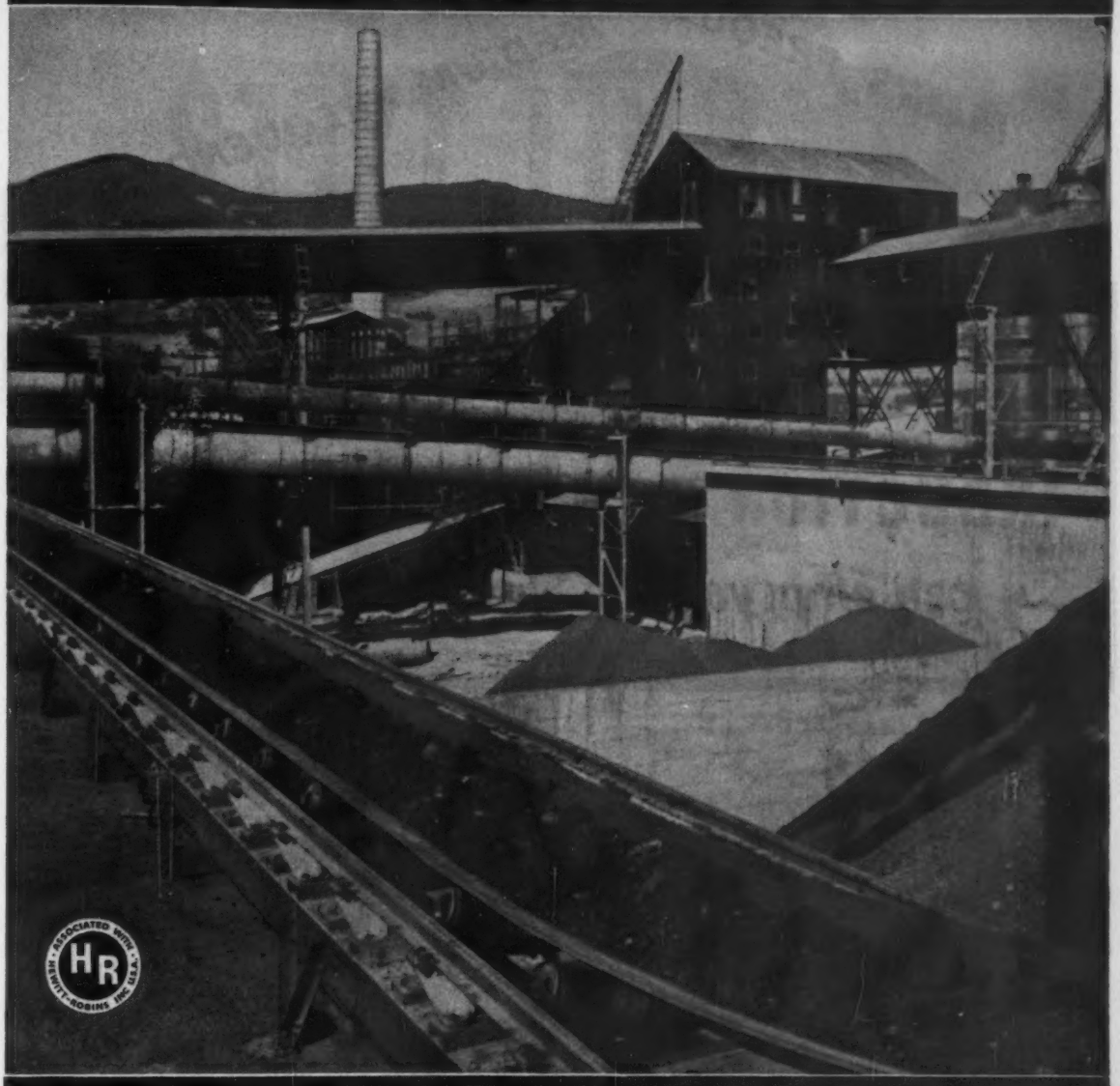

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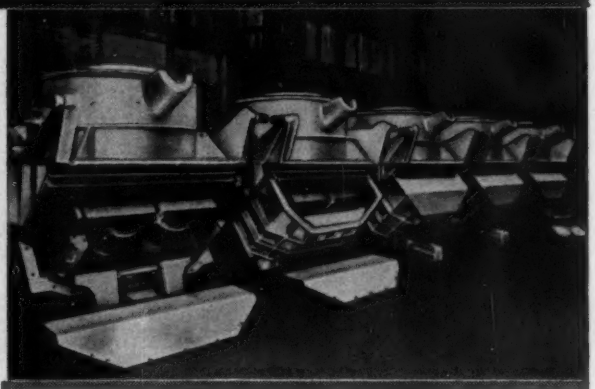

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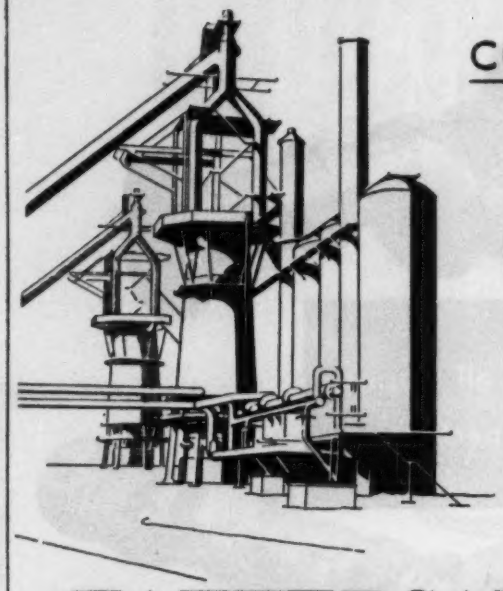

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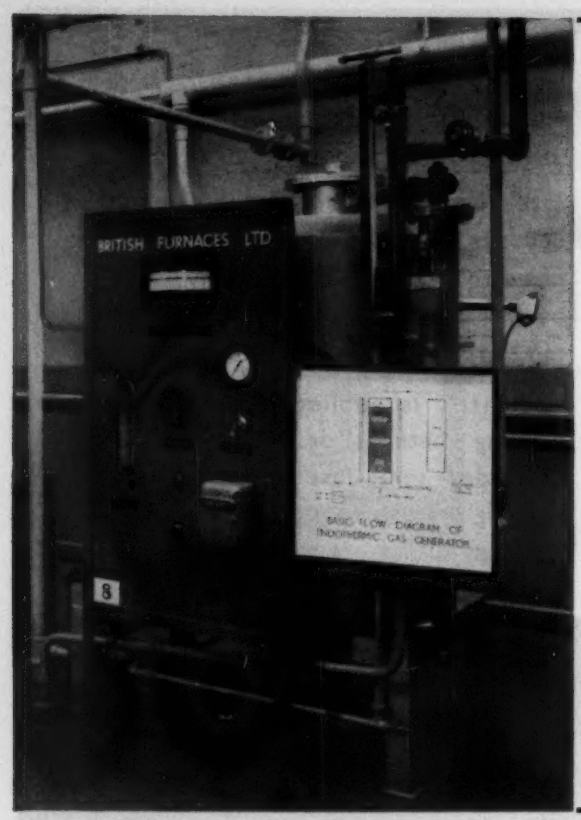


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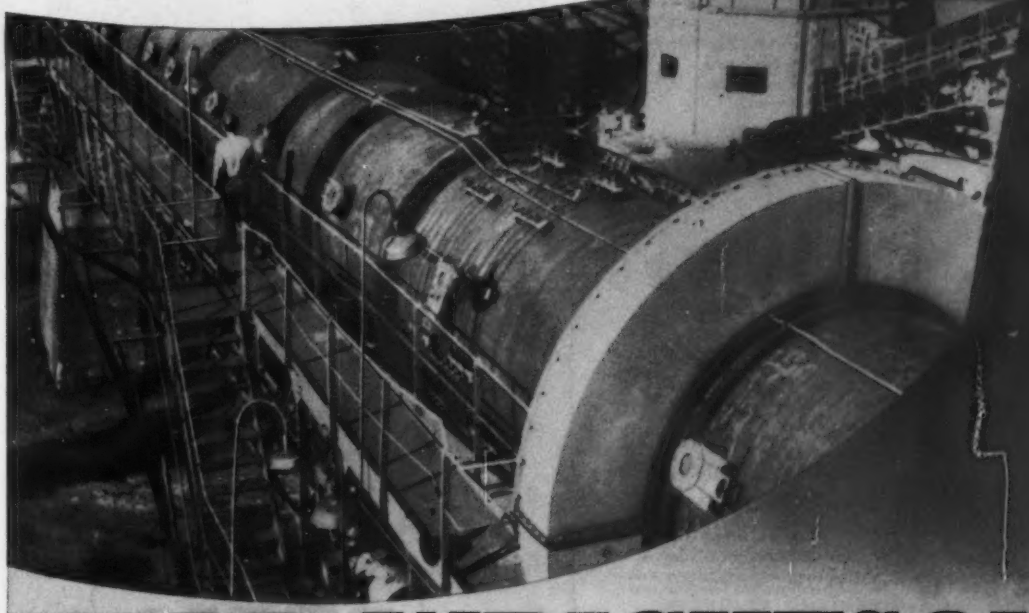

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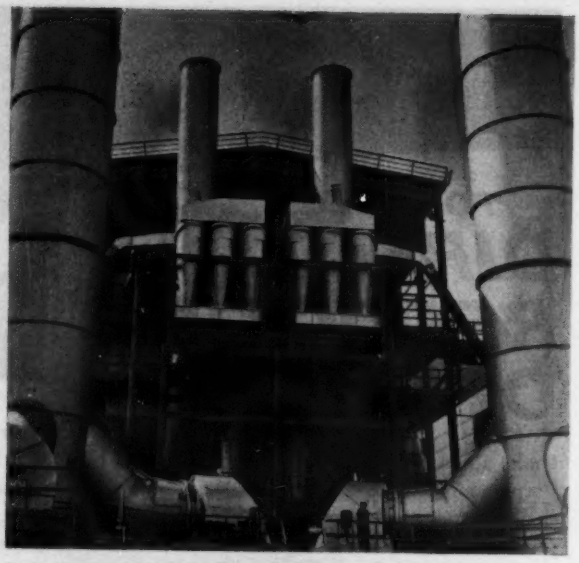

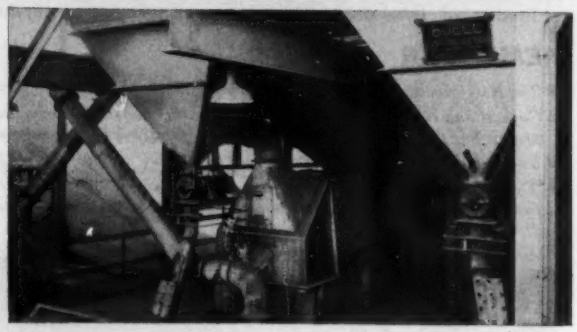

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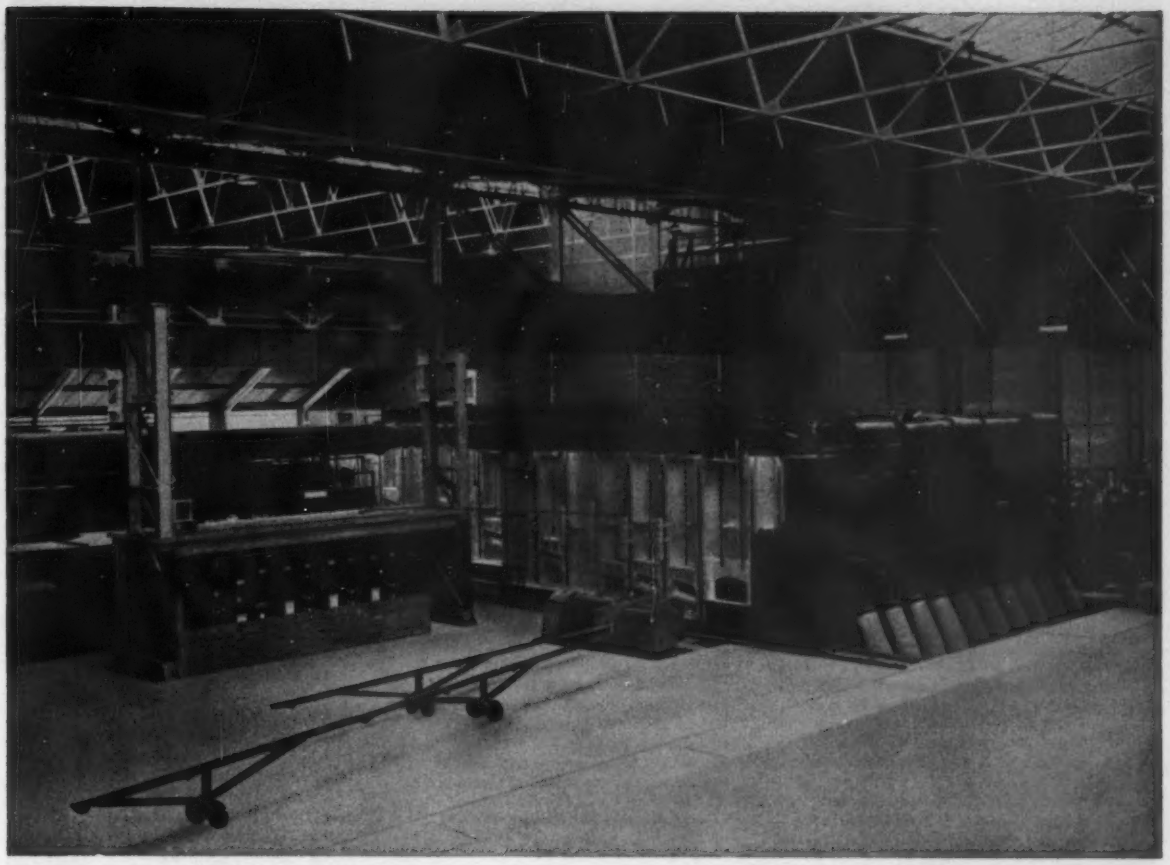

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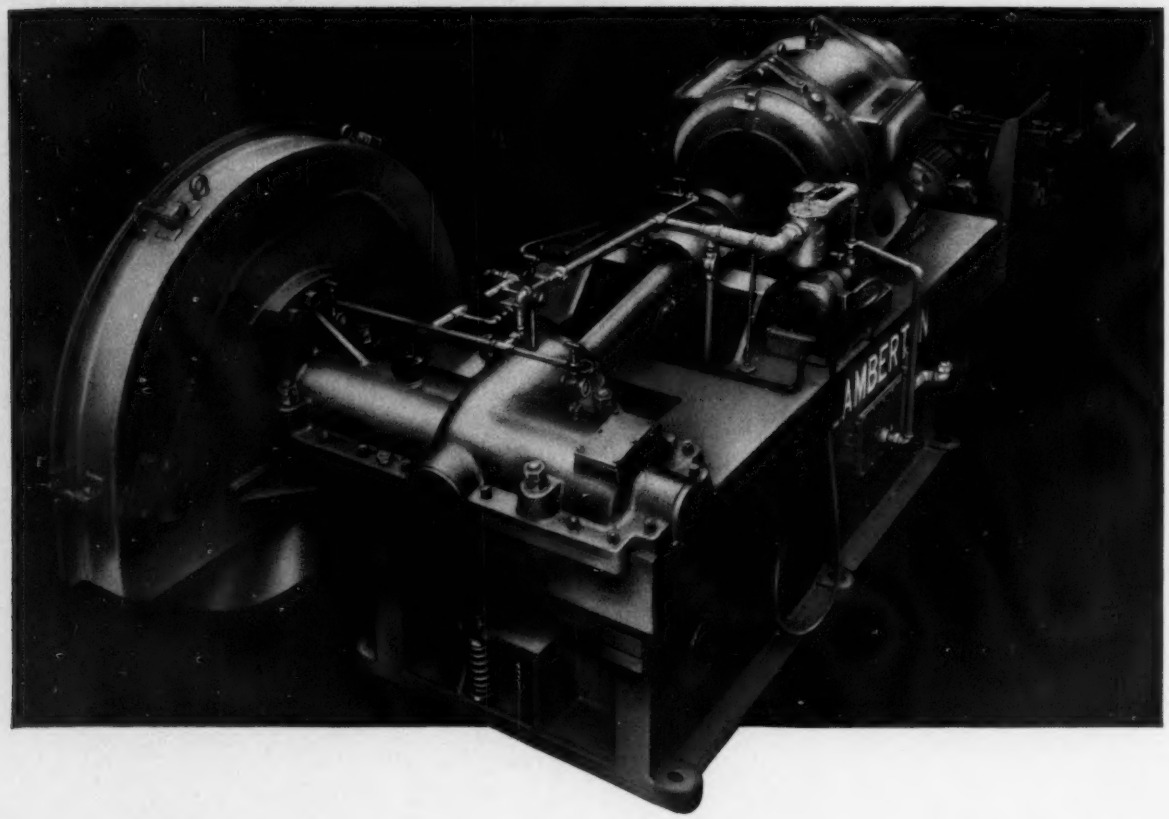

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